Nutrient Loading from Sanibel's Surficial Aquifer

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Executive Summary

A summary of the main findings in this study are presented in bullet form below. For a more complete discussion of these summarized points please read further.

- This study was the 3rd phase of development of the Sanibel Comprehensive Nutrient Management Plan. This study focused upon the surficial aquifer and its potential for nutrient loading to Sanibel's near-shore waters.
- For this study 52 wells were installed into the surficial aquifer of Sanibel. The perimeter of the island was the target of most well installations to be able to estimate groundwater flow on to or off the island. Level loggers were installed in wells to estimate groundwater flow, and samples were collected from the wells on four occasions over a year and analyzed for nutrient concentrations.
- This study (March 2015-February 2016) occurred during an El Niño event which brought unusually high rainfall to the study area during what would normally be considered the dry season. Results from this one year study should be considered in the context of about 60% more rain falling than during an "average" year.
- Estimated annual surficial aquifer groundwater flows discharging to surface waters from Sanibel were comparable in volume to annual stormwater discharges from Sanibel. High discharge areas included east end shorelines, end of Bailey Road, across from Murex Lakes, and the Sanctuary development.
- Groundwater discharge to Sanibel Slough was related to the controlled surface water level in the slough. After rain events hydraulic gradients would force groundwater toward the slough. During dry periods, the artificially high level of the slough would produce flow away from the waterbody through the surficial aquifer. A steady exchange of groundwater and surface water occurs along Sanibel Slough.
- In general, nitrogen (N) and phosphorus (P) concentrations in the surficial aquifer were greater than stormwater concentrations (which were investigated in Phase 2). Additionally, surficial aquifer N and P were much greater than SW Florida background surficial aquifer concentrations (Florida DEP monitoring network).
- Golf courses and wastewater holding land use types had significantly higher N and P concentrations than other land use types analyzed in this study.
- Loads calculated from flows and concentrations obtained during this study suggest annual loading of nitrogen from the aquifer to surface waters may be greater than annual stormwater loads, while phosphorus loads are about the same as stormwater.
- Results of this study confirm that surficial aquifer discharge volumes and nutrient concentrations are comparable to stormwater discharges and make groundwater an essential consideration in developing nutrient management plans.

Introduction

The Sanibel-Captiva Conservation Foundation (SCCF) Marine Lab identified a number of data needs for development of a comprehensive nutrient management plan for the City of Sanibel (SCCF 2013). Nutrient loading to nearshore and interior waters from Sanibel's surficial freshwater aquifer was recognized as an important component in the nutrient mass balance on the island. The surficial aquifer consists of the saturated part of the upper sequence of unconsolidated, unconfined sediments on Sanibel and is also known as the water table aquifer (Missimer 1976). A difference in water table level between spots in the surficial aquifer results in a hydraulic gradient. Water moves from the area of higher elevation to lower elevation through the aquifer. If the aquifer level is higher than sea level, water discharges off of Sanibel into the surrounding Gulf and sound ecosystems. Aquifer water levels usually vary significantly between seasons, being higher in the wet season (with higher rates of discharge from island) and lower in the dry season.

The work for this phase of the Sanibel Comprehensive Nutrient Management Plan included installation of groundwater monitoring wells, flow monitoring, water quality sampling, and data analysis. Periodic sampling provided water quality information for groundwater at each well and groundwater flow estimates are made based upon between–well pressure gradients estimated by depth loggers installed in the wells. Nutrient concentration data was integrated with flow data to provide nutrient loading estimates to the Gulf of Mexico, Pine Island Sound and Sanibel Slough. GIS-based analysis provided a large-scale view of nutrient hotspots and general groundwater flow characteristics. The results of this study are based on one year of monitoring from March 2015 through February 2016. Seasonal changes have significant effects on both surface and ground water quality. Dry season on Sanibel is normally from about October 15th through June 15th. On average, about 30-35 inches of rain falls in the wet season and 10-12 inches in the dry season. Due to a strong El Niño, the dry season of 2016 was very wet during the study period with 24.5 inches of precipitation (SCCF local weather stations) between October 2015 and the end of February 2016 compared to a historical mean of 8.9 inches (MesoWest Station TS755) during this period. Groundwater levels were as high for October through February (normal dry season) as they were in the wet season for this study. We adjusted our analysis to include the period of October 2015 through February 2016 as part of wet season. Due to this adjustment, a greater amount of data was collected during the wet season than dry season.

Methods

Monitoring wells were installed at 52 locations (Figure 1; Table 1) from January 2015 through February 2015 to provide perimeter coverage of the surficial aquifer discharge zone on Sanibel and to acquire information on aquifer characteristics for the interior of the island. Several well sites were added later in the project to provide additional data for aquifer interactions with Sanibel Slough and the eastern gulf shore of the island. Placement of monitoring wells focused on providing adequate information to estimate the flowrates of surficial groundwater exiting (or entering) the shoreline of Sanibel while staying within the constraints of a lean budget. Six wells were installed along Sanibel Slough to provide a picture of groundwater interaction with this waterbody. Most wells were installed as pairs to provide the hydraulic gradient information required to estimate groundwater movement. The monitoring wells consisted of 1.25 inch diameter PVC well points connected to sufficient length of PVC pipe to be inserted at least 1 meter into the surficial aquifer zone (Figure 2). A hand auger with up to 15 feet of extensions was used to drill the bore holes. Wells were installed during the dry season of 2014-2015 to take advantage of the lower seasonal water level and prevent water level dropping below well points later in the study. After initial installation, each well was developed by pumping at least 20 volumes of water using a Masterflex® tubing pump with 200 ml/minute capacity. A schedule was developed to sample each well (or well set) two times in the wet and dry seasons, allowing assessment of differences in concentrations and flows (Table 2). During each season the sites were scheduled to be sampled once after a rainfall event of at least 0.5 inches in previous 24 hours and once during a dry period of at least 7 days. The tubing pump was used to obtain samples after pumping a minimum of 4 well volumes (Figure 3). Samples were preserved per Florida DEP SOP 1000, and shipped to a NELAC certified laboratory for nutrient analyses within the allotted holding times. Samples were analyzed in the field for turbidity, dissolved oxygen, pH, salinity, and CDOM using an YSI EXO1 or EXO2 sonde unit.

To obtain well water depth for determination of hydraulic gradient between well sets, 12 Onset® hobo depth loggers (Figure 4) were deployed in wells for 1-2 week periods and then rotated to another 12 wells. The depth logger rotation schedule was designed to allow information to be collected on all sets of wells without the need to purchase data loggers for each well. Since the loggers were used in pairs to determine hydraulic gradient, the best matched pairs of loggers were determined by submerging all loggers in water of a constant depth and allowing them to log for two hours. The recorded depths of each logger were then compared to find the pairs with best matched results. These pairs were then used together for the duration of the study to minimize error in determining hydraulic gradient between wells. Data from the depth loggers was downloaded using an Onset logger shuttle in the field (Figure 5) and then downloaded to an SCCF computer from the shuttle using Hoboware® software. Depth data was compensated for differences in barometric pressure using barometer readings from the SCCF RECON GOM site in the Hoboware software. All depth data was adjusted to mean sea level (MSL) by adding a correction value unique to each well. Elevation relative to MSL for a reference point on each well was determined using a Trimble GEO7x GPS connected to Florida elevation base stations. A laser level was used to determine relative difference in elevation (and hydraulic gradient) between sets of wells.

Rainfall data was collected at our real time rain recording gage located adjacent The Dunes stormwater system weir off Sandcastle road. Rain data was analyzed simultaneously with well depth data to determine the effect of rain events on groundwater level. Tide data was obtained from the SCCF RECON station located at the mouth of Tarpon Bay. Tidal fluctuations were also evaluated simultaneously with groundwater depth data to determine the influence of tides on water level.

Flow estimates rely on subsurface hydrological data collected in previous studies by Missimer (1976) , Boggess (1974), Provost (1953), Fenton (1989), Johnson Engineering (1990 and 1987) and Dyer et al. (1990). These studies found variability in subsurface soils but shelly sand made up the majority of the surficial aquifer substrate. All of our well installations had at least some shelly sand in the surficial aquifer. Missimer (1976) measured surficial aquifer conductivity (k) and found it to range between 133 and 266 ft./day on Sanibel. He also noted that k near Sanibel Slough is likely 65 ft./day or less due to higher silt and organic content. Tests by DRMP (1990) for the City of Sanibel found saturated zone conductivity to be 245 ft./day in shell-sand deposits near the Center for Rehabilitation Of Wildlife and 109 ft./day in sandy soils near Sanibel Slough behind SCCF. They also found very low k (9.5 ft./day) at a former tree farm site which may have similar hydraulic conductivity to wooded areas of Sanibel. Following previous work by Missimer we used a conservative saturated zone hydraulic conductivity of 133 ft./day (40 m/day) for sand shell substrate sites along the Gulf coast of Sanibel, 65 ft./day (19.7 m/day) for sites with sand but less shell located along the Sanibel Slough and Pine Island Sound coast (and some interior sandy sites) and a k of 10 ft./day (3 m/day) for sites in wooded or heavily vegetated sites with some peat and less shell. Discharge estimates were determined by application of Darcy's Law. Discharge volume was estimated using the following equation:

$$Q= kA \, dh/dl$$

Where Q = discharge rate (volume/time), k = hydraulic conductivity, A = cross sectional area of aquifer, and dh/dl = hydraulic gradient. To obtain hydraulic gradient we installed two wells at each monitoring site separated by enough distance to obtain a head differential between the two wells. The continuously recording depth loggers provided water depth in each well simultaneously and a hydraulic gradient (dh/dl) was calculated between the sets of wells by taking the difference in depth divided by the distance between wells.

Mean surficial aquifer thickness on Sanibel was estimated to be 12 feet (3.6 m) by Missimer (1976). Other studies found surficial aquifer thickness to range between 12 and 20ft. and never more than 25ft. (Boggess 1974, Missimer 1989, Johnson Engineering 1987 and DRMP 1990). We used the 12ft. (3.6m) mean aquifer depth per Missimer, and DRMP. Wells were installed along the perimeter of Sanibel to be able to estimate discharge from the entire island by interpolating between well sites. The estimated cross sectional area needed to calculate discharge rate between each well site was equal to the half the distance between the adjacent sites (closest well on either side of site) multiplied by the 3.6 meter average surficial aquifer depth.

Nutrient loading rates were estimated by multiplying flow rates by nutrient concentrations obtained from sampling events at the well sites. GIS was used to show nutrient concentration and flow dispersion on Sanibel as separate map layers. A GIS layer was also developed to show the product of nutrient concentrations and flow rates (loadings) to better pinpoint the locations of higher nutrient transport associated with the Sanibel surficial aquifer. This information can be used to predict nutrient hotspots and possible sources. An annual total groundwater discharge rate was estimated from this work and concentration data was used to provide estimates of the mass of nutrients leaving Sanibel via groundwater.

A general linear model (GLM) ANOVA was used to evaluate possible factors influential in surficial aquifer nutrient concentration differences. Factors used in the evaluation included:

1. Wet/dry season
2. Rain/no rain event
3. Reclaimed wastewater irrigation/no reclaim water
4. Lake (or Sanibel Slough) proximity/no lake
5. Land use type
6. Fertilizer/no fertilizer period
7. Tide influence/no tide
8. Evapotranspiration.

Data was natural log transformed before running the GLM to meet the assumption of normal sample distribution. Sites were assumed to be influenced by lakes if they were within 60 meters (Missimer 1976), and the fertilizer ban period was between July 1 2015 and September 2015. Rainfall data and tidal fluctuation was plotted against water level data for each well and relationships were analyzed inferentially. From our evaluation, and as seen in other studies, tides were found to be influential in groundwater level fluctuations if a site was within 70 meters of the Gulf of Mexico or 150 meters of Pine Island Sound (Provost 1953). Reclaimed irrigation water was used as a factor if at least 1 million gallons/year were used within 100 meters of a site. Evapotranspiration rates were estimated by calculating mean water level drawdown in aquifer levels during daylight hours. Water table drawdown over 10% was categorized as the greatest rate, with other categories for 5-10%, 1-4% and 0%. Comparison of differences in nutrient concentrations between wet and dry seasons was accounted for in the study design; however dry season was expected to follow historical patterns (October 15th through June 15th or July 1st).

The period from October 2015 through the end of the study in February 2016 could not be considered “dry” due to rainfall nearly 3 times the average during this period (Figure 6), keeping the surficial aquifer at wet season levels. Therefore the period from October 2015 through the end of this study was evaluated as part of the wet season instead of the originally planned “dry” season. This caused an unbalanced distribution of water quality samples which affected the power of some of our analyses – especially when comparing differences between wet and dry season. Therefore statistical analyses were not as strong as planned for detecting true differences between dry and wet season.

Interpolated maps illustrating nutrient concentrations, flow rates and nutrient loads from Sanibel were prepared using ArcGIS 10.1. The inverse distance weighing (IDW) method was applied to produce groundwater flow rate (and loading) interpolations using only the two closest data points as neighbors. This method more accurately portrays the total discharge calculations which were made along the perimeter of Sanibel (estimates from interpolation between perimeter sites). IDW was also used for nutrient concentration interpolation using 8 neighbors to form the interpolated surface.

Results and Discussion

Rainfall during the study period (March 2015-February 2016) was over 69 inches as compared to mean annual rainfall of about 42 inches (60% greater volume). The expected dry period from October through February was evaluated as part of the wet season due to 3 times greater rainfall than average during this period. The results found here should be evaluated in the context of this unusual rainfall volume brought on by the El Niño event during this study period.

In general all well sites located within 70-150 meters of the shoreline were influenced by tide (Figure 7), while wells greater than 150 meters from shore were not. Similar relationships between tides and groundwater level were also found by Provost (1953). All wells showed increased water depth during significant rainfall events (Figure 8). This relationship for Sanibel's surficial aquifer is well documented by Boggess (1974), Missimer (1976), and Provost (1953). The effects of evapotranspiration on water level were also evaluated by reviewing water level for diurnal patterns not associated with tides. Studies (Mazur et al. 2014) have identified normal diurnal patterns of water level drawdown during the daytime in areas where evapotranspiration has significant effects on surficial aquifer levels. This pattern is evident in many of the monitoring wells (Figure 9) and especially prevalent in interior wells surrounded by vegetation. Irrigation effects may be difficult to separate from ET effects as irrigation normally occurs during the non-daytime period which is the same time at which ET is small and aquifer levels rebound after a daytime drop.

Using the Darcy's Law equation and assumptions outlined in the methods section, estimated total annual discharge of water from Sanibel Island to adjacent surface waters is 4.824

million cubic meters (Table 3). Of this, 3.51 million cubic meters flowed into the Gulf, 1.08 million cubic meters to Pine Island Sound and 240,000 cubic meters to the Sanibel Slough (Table 4). These estimates show that surficial groundwater discharge volumes are significant relevant to Sanibel stormwater runoff estimates made in Phase 2 of this long term project (Figure 10). Groundwater discharge into the Gulf is 3.6 times the volume of stormwater (981,488 m^3) leaving Sanibel for the Gulf, 42% of the stormwater discharging into Pine Island Sound (2.57 million cubic meters) and 13% of stormwater flowing into the Sanibel Slough (1.81 million cubic meters). Overall groundwater discharge estimated for 2015-2016 was 86% of the mean annual stormwater discharge estimated in Phase 2 of this study (Figure 10; Thompson et Al. 2015). This estimate should be evaluated in the context of the strong El Niño which produced greater than average rainfall in 2015-2016, but clearly groundwater flowrates are significant and comparable to stormwater runoff volumes. This makes sense in light of the Sanibel specific runoff coefficients produced in the previous study. For Sanibel overall, approximately 32% percent of rainfall (Thompson et Al. 2015) was estimated to discharge as sheet flow, leaving 68% to percolate into the surficial aquifer or to be lost through evapotranspiration and interception. At this estimated total groundwater discharge rate (for 2015-2016), approximately 28% of Sanibel's rainfall is lost through discharges into surface waters through the surficial aquifer. The remaining 40% would be stored in deeper aquifers, lost through evapotranspiration or pumped and used as irrigation.

Wet season groundwater discharges were significantly greater than dry season for groundwater monitoring sites on the Gulf perimeter (paired t-test, sq.rt. transformed data, $p = 0.001$, $T = 6.5$) (Figure 11) and for sites on the Pine Island Sound perimeter (paired t-test, sq.rt. transformed data, $p = 0.001$, $T= 13.2$) (Figure 12). The pattern for sites on the Sanibel Slough were reversed with dry season groundwater flows greater than wet season flows (paired t-test, square root transformed data, $p = 0.001$, $T= 4.1$) (Figure 13).

Rainfall increases the hydraulic gradient (and discharge rate) at all groundwater sites discharging to waterbodies which have uncontrolled water levels. The water level in the Sanibel Slough is held artificially high by control structures and is only released in times of flooding. This produces an artificially large hydraulic gradient (and discharge rate) away from the slough during the dry season. During the wet season the groundwater level rises to meet slough water levels and the gradient is reduced. An illustration of the relationship between the controlled water level of the Sanibel Slough and adjacent surficial groundwater is shown in Figure 14. The well adjacent Sanibel Slough has a groundwater elevation greater than the one 60 meters away due to the controlled high water level. In this situation the hydraulic gradient is away from the slough and groundwater travels away from the slough (Figures 14 and Figure 15). As rainfall enters the surficial aquifer, groundwater levels rise more quickly than surface water levels, which is normal due to pore space in soil filling more rapidly (Figure 14). The hydraulic gradient reverses and groundwater flows toward the slough (Figure 16). After the rain event, groundwater levels recede, and the artificially high water level in the slough causes groundwater to begin flowing away again (Figures 14 and 15). Previous studies have shown that surficial groundwater adjacent to lakes and other waterbodies normally flows toward the waterbody due to greater ET at the waterbody (Sacks et Al. 1998, Missimer 1976, Boggess 1974).

GIS-based interpolated maps of groundwater flow patterns derived from data gathered during this study show a general pattern of flow off Sanibel and into the Gulf of Mexico and Pines Island Sound over the eastern portion of the island and on to the island (tidal influx) in the western portion (Figures 17 and 18). The limited distribution of flow measurement sites result in coarse interpolations of actual flow patterns across the whole of Sanibel. However significant groundwater discharge areas were found along the eastern Gulf shore of Sanibel, at the end of Bailey Road, and northeast of the Sanctuary development and golf course (Figures 17 and 18). The organic content of the soils north of Sanibel Captiva Rd. reduce flowrates in that area (lower conductivity). The shelly sand beach soils allow for greater flows at those sites, however greater surficial aquifer discharge rates seem to be correlated with greater development (Figures 17 and 18). With development comes reduced evapotranspiration and greater irrigation. The three golf courses have high irrigation rates but groundwater discharges (into near shore waters) from those areas are less than beach sites due to the organic content of the soils and vegetation (Table 4).

104 water quality samples were collected at the groundwater monitoring sites per the pre-determined schedule (Table 2). Notably high concentrations of both nitrogen and phosphorus were found at the golf course sites (SGW 13, 17, 27, 29, 30, 40), adjacent to the reclaimed water ponds (SGW 35, 36, 37, 38) and the site adjacent to a wastewater lift station and former wastewater treatment plant in Gumbo Limbo (SGW25) (Table 5, Figures 19-22). Inorganic nitrogen is a more important pollution indicator than total nitrogen because it is immediately available for primary production (algae, etc.) after discharge to surface waters whereas organic

nitrogen in groundwater is mostly dissolved organic matter (DOM) and not readily available for uptake by primary producers. The decomposition of plant matter in and on soil is the main source of DOM in the surficial aquifer. Inorganic nitrogen at the golf course sites was 3-60 times as high as the mean surficial aquifer background concentration for southwest Florida (0.34 mg/l) (FLDEP 2016; Figure 19).

Reclaimed wastewater has relatively high levels of orthophosphate (about 3 mg/l per Sanibel Public Works). The levels of OP found at the golf courses (which irrigate with reclaimed water) and at the reclaimed water pond sites are 10 to 25 times higher than the mean southwest Florida surficial aquifer background concentration (Florida DEP 2016). The site adjacent the Gumbo Limbo lift station (SGW25) was over 20 times the background concentration. The overall mean concentrations of TP, OP, TN and IN in Sanibel's surficial aquifer are 2-5 times the southwest Florida mean surficial aquifer background concentration (Table 5; Figures 19-26; Florida DEP 2016).

Each monitoring well site was classified by land use type (Table 6), and mean nutrient results compared using GLM ANOVA (Figure 27-30). The main objective of site placement was to provide estimates of nutrient loading from Sanibel's surficial aquifer, thus we did not have a balanced distribution of well sites by land class. However statistical comparison was still possible and significant differences were found when comparing results from wells on different land classes. The two monitoring wells (35 and 37) adjacent the reclaimed water holding ponds were classified as WWTP land class type due to their unique location. After a few months of monitoring, well 25 at the west end of the Gumbo Limbo subdivision was also classified as WWTP due to its close proximity to the wastewater lift station and a WWTP formerly located there due to the high nutrient concentrations found during sampling. Samples collected there had the highest mean phosphorus (2.54 mg/l) levels of all sites and very high ammonia (1.76 mg/l), both suggesting a nearby "source" or legacy source of nutrients. Domestic wastewater from the nearby lift station was the first consideration; however current neighbors were contacted to see if a community garden or other possible source may have been located on the site at one time. We also suggested that facilities from a past package wastewater treatment plant for the Gumbo Limbo development may have been near the site. A document was found (Florida PSC 1992) which highlighted operating problems associated with the former Gumbo Limbo wastewater treatment facility including: aeration basin overflows, perc pond capacity exceedance, severed and leaking influent wastewater lines, perc ponds overgrown with pines, extreme capacity exceedance, and an abandonment of the facility by the original owner in 1988 (with an auction of land necessary to expand the plant to meet capacity requirements. The City of Sanibel's Public Works Director latter confirmed that the old Gumbo Limbo wastewater treatment plant was located on that site.

Nitrogen in raw domestic wastewater is primarily in the form of ammonia with concentrations from 30-50 mg/l or more (Bicki et Al. 1984; Thompson, 2011 SCCF data). Ammonia nitrogen is fairly immobile in organic-rich soils such as those at the Gumbo Limbo monitoring site due to the soil's cation exchange capacity (Reddy et Al. 2010). However it is a great fertilizer for plants. Our findings of high TN and relatively high ammonia in that site's groundwater reflect the immobility of the original ammonia from the raw wastewater inputs (spills), and the uptake of that ammonia by plants which converted it to the organic nitrogen (shown in the high TN values). Phosphorus is also (relatively) immobile in soils and we see the highest levels of TP in the groundwater at this site also due to those legacy wastewater nutrient inputs. Sites which had package wastewater plants with similar problems before Sanibel's WWTP came on line may exhibit similar high concentrations of nitrogen and phosphorus due to legacy inputs. Septic systems or on-site wastewater treatment and disposal facilities (OSTDs) were previously the main method for disposing of domestic waste on Sanibel before the City installed the centralized sewer and treatment system. Legacy nutrients form these OSTDs may still be contributing to the total nutrient load exiting Sanibel (through groundwater).

Inorganic nitrogen (IN) was highest in the surficial aquifer near golf courses (1.1 – 20.9 mg/l, Table 5), averaging about 8 times higher (7.9 mg/l) than other land classes except for the WWTP land use (2.14 mg/l) (Figure 27). However the main component of the IN was ammonia which is characteristically immobile in soils (IN = ammonia + NOx). Nitrate, the mobile form of IN in groundwater (NOx) was much lower than ammonia for golf courses (Table 5). The anaerobic, wetland characteristics of the soil surrounding the well installations near the golf courses were likely responsible for the partitioning of inorganic nitrogen as mostly ammonia. Fertilizer applied to the golf courses in ammonia form is not readily converted to the mobile NOx form due to poorly aerated soil.

A statistically significant greater concentration of IN and TN was found in golf course samples than other land use type except WWTP (Figure 28; Table 7). TP and OP were also significantly greater for golf courses than high, medium, and low density residential and natural land classes (Figures 29 and 30; Table 7). The WWTP land class had statistically greater levels of TN, IN, TP and OP than low, medium and high density residential lands as well as the natural land class (Table 7).

The high concentration of nutrients in the surficial aquifer beneath golf courses can be attributed to fertilizer use, irrigation with reclaimed wastewater, low hydraulic conductivity, and poorly aerated soils. Aquifer monitoring sites on lands classified as WWTP and adjacent Sanibel's treated wastewater holding ponds are likely measuring transport of nutrient enriched water through the groundwater. Treated wastewater can have between 4-6 mg/l TN and 2-3 mg/l TP (data supplied by City of Sanibel, 2014) which are high values relative to water quality criteria.

Principal component analysis of similarity (PCA, Primer 6®) was performed using mean nutrient concentrations and groundwater flow rate and outcomes were grouped by land class types. Those sites closest together in the PCA plot are most similar (Figure 31). In general, the PCA grouped golf courses and WWTP sites near the higher nutrient concentration side of the plot, and natural sites near the lower concentration side of the plot (Figure 31). Residential land uses also grouped together. These groupings further illustrate findings discussed above.

Reclaimed wastewater contains high concentrations of nitrogen and phosphorus and is used to irrigate golf courses and some commercial and residential land. Comparison of groundwater samples taken from wells installed on lands which average over 1,000,000 gallons of reclaimed water use annually showed statistically significant higher mean TN, IN, TP and OP, (Figures 32-35, Table 7). In phase 2 of this study (Thompson, 2014), mean OP concentrations were found to be higher in stormwater runoff from reclaimed water irrigated sample sites. Golf courses use about 75% of reclaimed water consumed on Sanibel. This equates to about 260 million gallons each year spread equally between the three golf courses. This study supports previous work on Sanibel which identified irrigation with reclaimed water as a major source of nutrient load to the environment. PCA analysis grouped reclaimed water irrigated sites at the higher concentration (but moderate flows) end of the plot (Figure 36).

After removing golf courses from the comparison of nitrogen and phosphorus between sites irrigating with reclaimed water and those not using reclaimed water, no significant differences could be found (GLM ANOVA). Golf courses use over 75% of the reclaimed water consumed on Sanibel. The next largest individual user of reclaimed water on Sanibel uses only 1/10th of the volume of a golf course. Since golf courses use such a majority of the reclaimed water, collinearity exists in the GLM evaluation of land use types and reclaimed water use (model cannot be run evaluating interaction of these two factors). This condition makes identification of the main effect less clear. It cannot be determined if the significantly greater concentrations of nutrients in aquifers beneath golf courses is due mainly to fertilization on the golf courses, or reclaimed water use or both.

Mean dry season IN and TP in the surficial aquifer were significantly greater than the mean wet season concentrations (Table 7). Phase two results found higher nitrogen concentrations in dry season stormwater runoff than wet season. Taken together, these results suggest that fertilizer applied during dry season (but banned during wet season) have a significant impact on both stormwater runoff and the surficial aquifer which collects a substantial portion of rainfall volume. Slightly greater volumes of reclaimed water are also applied during the dry season. Due to the disproportionate number of groundwater samples taken during the unusual wet season during this study, the power of the statistical analysis was not as robust as planned. Differences in TN and OP may also have been found with a greater number of dry season samples.

Mean salinity was found to be less at sites near lakes (Table 7). The salinity relationship between lakes on Sanibel and the surficial aquifer was discussed by Boggess (1974). He states that the salinity of some Sanibel lakes is inversely related to groundwater level. Local groundwater flow is usually toward lakes due to higher evapotranspiration rates, but during dry season lake levels may become higher than water table levels and the flow can be reversed (Sacks et Al. 1998). Significantly greater concentrations of IN and TN were found at sites within 60 meters of a lake of over 1 acre surface area (Table 7). Higher nitrogen concentrations at sites near lakes may be explained by the tendency of the lakes to be located on land use types which have significantly greater nutrient concentrations. Lakes collect stormwater runoff and most of the lakes in this evaluation were located in developed areas with golf courses. Concentrations of total nitrogen and total phosphorus in The Dunes stormwater system (lake) is significantly less (GLM ANOVA, $p = <0.001$, $t = 76.1$ (TN), $t= 57.8$ (TP)) than concentrations in the surficial aquifer (Figure 37). Sanibel lakes are currently being sampled and analyzed for nutrients under the next phase of the comprehensive nutrient management plan development. Information obtained from that effort will allow more thorough evaluation of the relationship of community lakes to the Sanibel environment.

Statistically significant lower concentrations of TN, TP and IN were found at sites influenced by tides (Table 7). Colored dissolved organic matter (CDOM) was also lower at these sites. The diluting effects of the tide are likely the reason for this finding. However, the highly aerated shelly sand shoreline sites may promote more mobile nutrient species, preventing accumulation of nutrients in the soil which occurs at sites with greater organic content. In general, these sites exhibit greater groundwater flow rates, helping to flush the nutrients to adjacent surface waters.

Sites with higher rates of evapotranspiration were found to have significantly greater concentrations of TP, OP, TN and IN. A Spearman's correlation analysis found a significant but weak positive relationship between evapotranspiration and nutrient concentrations (r^2 from .14 to 0.27). Higher rates of evapotranspiration were associated with sites which were densely vegetated, having greater organic content in the soil. The higher ionic holding capacity of organic soils combined with lower aeration, helps immobilize nutrients, holding them in place and producing higher local concentrations. Salinity was also significantly greater at sites with higher evapotranspiration. Boggess (1974) and Provost (1953) both found interior vegetated habitats to have higher salt content. The dewatering of soils by evapotranspiration concentrates salts and lowers the local freshwater lens on the water table. As the freshwater lens drops, the higher salinity layer below is exposed. This process increases salinity of these sites over years and years of the process.

Surprisingly, no significant difference was found for surficial groundwater nutrient concentrations for periods immediately following rain events compared to those after a period of at least 7 days of no rain (Table 7). Rainwater percolating through the soil with pollutants gathered from terrestrial environments might were theorized to immediately increase concentrations of nutrients in the surficial aquifer. However, as found in phase 2 of the nutrient management plan development, mean stormwater concentrations of nutrients are often less than mean surficial aquifer concentrations. Soils with organic content and high exchange capacity can concentrate nutrients (Follett, 1995).

Maps of nutrient concentrations (and loads) in the Sanibel surficial aquifer were developed using ArcGIS10 interpolation methods (Figures 38-42). Though these maps can be used to get a good general feeling for concentration distribution over the island, they are based on a small number of samples relative to island size. Interpretation of concentrations on a detailed scale using these maps should be done with caution. Actual concentrations are only known at sample sites (shown as triangles), and are study period dependent.

Mean surficial aquifer salinity was lowest in those areas with greatest off-island flow, near eastern shorelines and beach areas, mid island beaches and the sanctuary (Figure 43). Provost had similar findings in 1953 stating the freshest waters were near the Gulf and saltiest near vegetated interior sites. Boggess (1974) found the highest salinity in groundwater on the north half of island. Our findings were similar with high salinities in the wooded low areas north of Sanibel Captiva Road (Figure 43). High salinity groundwater was also prevalent around Bowman’s Beach and Clam Bayou. This is likely due to the constantly changing coastal morphology of this area. Blind Pass has migrated many times in recent history, sometimes bringing tidal salt water through this area.

Interpolated concentrations of surficial aquifer IN are shown in colored contours from blue (low concentration) to red (high concentration) (Figure 38). The contour scales were set at levels relevant to potential environmental impact. Studies (USGS 2009, Reilly et al. 2015) have revealed natural background concentrations of NOx and ammonia in Florida surficial groundwater to be about 0.2 mg/l for each constituent and the Florida surficial aquifer monitoring network results use 0.34 mg/l IN as the natural background concentration for SW Florida (Figure; 23 Florida DEP 2016). Concentrations at or below this level were shown in blue in the GIS analysis. The national median concentration for surficial groundwater was 1.85 mg/l for NOx and 0.24 mg/l for ammonia (USGS 2009). In addition, USGS found the highest concentration of ammonia to be 0.4 mg/l for Florida citrus lands. Based on this information 2.4 mg/l IN was classified as high (reddish) while 2.0 mg/l was high for NOx. The interpolated maps show most of Sanibel’s surficial aquifer to be low in the more mobile NOx (Figure 39) while high in the largely immobile ammonia nitrogen (Figure 38). Ammonia is associated with fertilization as well as organic degradation activity in hydric wetland soils prevalent on Sanibel. Ammonia nitrogen surrounded by hydric soils is slow to be oxidized to NOx, keeping it fairly immobile (Bohlke 2006). The interpolated maps show the highest concentrations of surficial aquifer IN around golf courses, WWTP land uses and development in general.

The interpolated TN map (Figure 40), reflects the IN map, however much of the TN in groundwater is contributed by CDOM. The Sanibel surficial aquifer is high in CDOM, averaging 580 QSE across all project sites compared to the mean CDOM value of 78 QSE for the Caloosahatchee River at Ft Myers (SCCF RECON). A significant and moderately strong relationship exists between Sanibel's surficial aquifer TN and CDOM ($r^2 = 0.48$, $p < 0.001$). Golf courses, WWTP and areas of highest development density were interpolated to have highest TN values for the surficial aquifer.

Phosphorus is less mobile in groundwater than nitrogen. Inorganic phosphorus (OP) in the surficial aquifer was highest for golf course and WWTP (adjacent reclaimed water ponds) land use types (Figure 41). Interpolated maps of surficial groundwater OP concentrations made in ArcGIS 10 have contours from blue (low concentration) to red (high concentration). The contour scales were set at levels relevant to potential environmental impact. Studies (USGS SOFL 2009; FLDEP 2016) have revealed natural background concentrations of OP in Florida surficial groundwater to be about 0.02-0.04 mg/l. National median concentrations were 0.01 mg/l OP over all land classes. Concentrations at or below background levels were shown in blue in the GIS analysis, while high concentrations were more reddish. The highest mean OP concentration in Florida surficial aquifers was about 0.79 mg/l for citrus lands (USGS SOFL 2009). The GIS interpolation predicts a large portion of mid-eastern Sanibel Island (associated with golf courses, reclaim water storage and lift stations) to exhibit high levels of OP in the surficial aquifer reaching some of the highest levels reported for the DEP Florida data.

TP results mirrored OP results (Figure 42). On the average, OP accounted for more than 90% of phosphorus in the filtered samples. This was expected as phosphorus is easily bound to soil and the methodology for determining OP selects for dissolved phosphorus. Soil acts as a filter for phosphorus. Again TP is shown to be a concern near the golf courses and WWTP land use types.

An interpolated map of surficial aquifer salinity was also produced (Figure 43). In general the lowest salinities are found in areas where groundwater flow is greatest (refer to Figure 18) and highest salinities where flow was found to prevail onshore or evapotranspiration was greatest. These interpretations are sensible according to previous discussion in this document.

Impacts that surficial groundwater discharges have cannot be estimated based on concentration or flow data alone. Areas with high concentrations of nutrients sometimes have low discharge rates, while areas with high discharge rates can have low nutrient concentrations. Evaluation of loading rates provided a more accurate representation of areas of concern related to nutrient discharges to adjacent surface waters.

GIS-interpolated maps of surficial aquifer nutrient loads to adjacent surface water give a more accurate picture of nutrient "hotspots" on Sanibel. For all nutrients, wet season generally has higher loading rates from all areas due to significantly higher discharge rates. For all nutrients and both seasons; The Dunes, Wulfert Point and eastern Sanibel have relatively greater loading rates than the remainder of the island (Figures 44-50). These rates are due in large part to golf course surficial aquifer concentrations. Areas south of Casa Ybel stretching to near Murex Lakes become significant contributors of either IN or OP (the nutrients of biggest concern) depending on season (Figures 44, 45, 48, 49).

The area at the end of Bailey Road also produced a high loading of both nitrogen and phosphorus due to a large flow rate. This finding fits with a previous interpolated surface water map indicating high IN concentrations in San Carlos Bay near the shore of Sanibel (Thompson 2013). The source of those concentrations may be the surficial aquifer discharge in this area.

As previously stated, 3.51 million cubic meters of groundwater was discharged from Sanibel Island in 2015 to the Gulf of Mexico, 1.08 million cubic meters to Pine Island Sound and 0.24 cubic meters to the Sanibel Slough for a total surficial aquifer discharge of 4.83 million cubic meters (Table 3). Using the aquifer nutrient concentrations and aquifer flows obtained for wet and dry season, the loading rate to waters adjacent Sanibel was 3840 kg./yr. for IN, 12,188 kg./yr. for TN, 989 kg./yr. for OP and 1, 170 kg./yr. for TP (Table 3; Table 8). The estimated nitrogen loading values associated with groundwater discharges are considerably greater (2.5 times for IN) than estimates of loadings from stormwater runoff (Figures 51 and 52), while the estimated loading of phosphorus is about the same as stormwater estimates (Figures 53 and 54).

Principal components analysis of loading rates for land use types groups the golf course and WWTP sampling sites together with similar large loading rates of all nutrients (Figure 55). PCA analysis also shows reclaimed water sites as contributing higher total nutrient loads (especially the golf courses) (Figure 56).

A comparison was made of groundwater nutrient concentrations verses Sanibel Slough concentrations at the three monitoring sites located adjacent Sanibel Slough (Figure 57). In general groundwater concentrations were much greater than the mean surface water concentrations (Figures 58 and 59). When stormwater is compared to both groundwater and surface water an interesting relationship is seen. For TN, stormwater dilutes the aquifer loading to the Sanibel Slough and this effect can account for lower concentrations of TN in the slough than in the groundwater (Figure 60). However for TP (Figure 61), stormwater runoff has higher concentrations than the Sanibel Slough or aquifer and can be explained by the tendency of phosphorus to adsorb to soil and sediment particles. Phosphorus is filtered from water flowing over or through soil due to the soil's ion exchange capacity.

Higher nitrogen concentrations in groundwater than stormwater can be explained by the dynamics of stormwater runoff and rain percolation through the soil. Only about 60% of rain events on Sanibel between 2011 and 2013 produced runoff (Thompson et Al. 2014). About 40% of the events produced no runoff because modeling suggests it takes 0.3-0.5 inches of rain to produce stormwater runoff (Thompson et Al. 2014). The initial water volume during a rain event pools on surfaces, evaporates or percolates through the soil before any runoff begins. The main source of nutrients in runoff or groundwater is terrestrial applied fertilizers, animal waste or irrigation with reclaimed waters. The initial flow of water from a rain event will pick up any nitrogen and phosphorus accumulated on the terrestrial surface and move these nutrient loads through the ground in the form of percolation. Only later, when the ground becomes more saturated with rain, will stormwater runoff actually occur. Irrigation may not produce any runoff but produces large amounts of percolation through the soil. Irrigation water moves nutrients through the soil (and may contain its own high load of nutrients if its source is reclaimed wastewater) and into the groundwater similarly to the first water from a rain event. Surface water runoff samples will not have lower concentrations of nitrogen than groundwater because the first flush of rainwater containing greatest nutrient concentrations typically percolates through the ground.

Summary

This study has shown that nutrient loading from surficial aquifer discharge is at least as important as nutrient loads from stormwater runoff. Estimates of stormwater runoff coefficients in Phase 2 of this project showed about 30% of the total rain falling on Sanibel exits Sanibel as stormwater runoff. This leaves about 70% of annual rainfall to percolate into the surficial aquifer or to be lost as evapotranspiration. Total nitrogen load from Sanibel's groundwater is estimated to be over 2 times greater than its stormwater runoff. Phosphorus loads for aquifer discharges are about equal to stormwater runoff estimates. Typically, concentrations of nutrients found in the surficial aquifer are equal or greater than concentrations found in stormwater. Fertilizer, reclaimed water and other sources of nutrients are preferentially transported to groundwater via storm events or high water table levels and soils often help to concentrate nutrients with their ion exchange capacity. Nutrient management activities must consider the pathways nutrients will take to the ultimate receiving waterbody and reduce this transport. Legacy nutrients associated with historical septic systems and OSTDs will continue to affect the groundwater aquifer and consequently local surface water for an unknown period after stormwater-based management activities are implemented.

Golf courses and reclaimed water are two factors found to be associated with higher nutrient concentrations and loading rates from the surficial aquifer. Golf courses fertilize and use nutrient-laden reclaimed water for irrigation. To reduce loadings from these sources, a reduction in discharge of reclaimed water and usage of fertilizer is warranted.

The WWTP site adjacent to the Gumbo Limbo wastewater lift station had the highest concentrations of OP and relatively high concentrations of nitrogen indicating there may be some association with wastewater. Investigation showed the leaking Gumbo Limbo wastewater treatment plant was located adjacent the monitoring site until 1993. Spillage, leakage and maintenance issues with the plant are almost certainly the source of higher nutrient concentrations found at that site. This is one example of how legacy nutrient loadings can impact current water quality.

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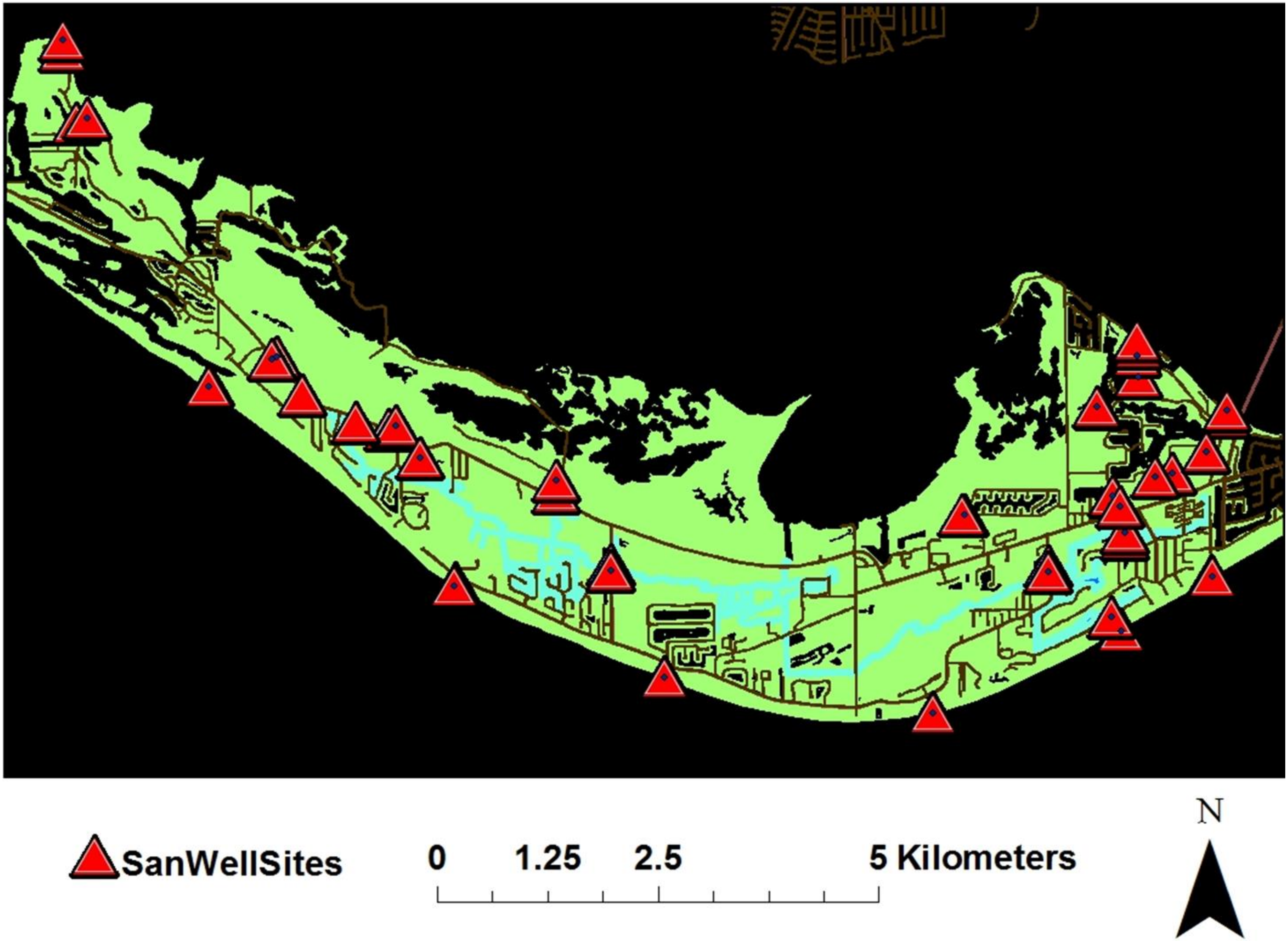

Figure 1. Location of 52 wells installed for this study. Most wells were installed in pairs and the scale of this map does not allow resolution of each well when they are in close proximity.

Table 1. Information for monitoring wells installed during this study.

Site	Description	Install Date	Lat	Long	Depth to Stop (m)	Stop Elevation MSL (m)	Upgradient Well	Distance from Gulf/Sound (m)	Distance from Lake/Slough (m)	Irrigation - Reclaimed Water
GW01	EndofBeachRd_GulfBeachUpstream	2/11/2015	26.437308118	-82.039754992	2.148	-1.147		42		N
GW02	EndofBeachRd_GulfBeachDwnstrm	4/21/2015	26.437150000	-82.039660000	2.398	-1.103	GW01	23		N
GW03	SundialEastCondo_GulfBeachUpstrm	2/20/2015	26.431665119	-82.050101431	2.134	-0.235		32		N
GW04	SundialEastCondo_GulfBeachDwnstrm	12/11/2015	26.431527369	-82.050019310	1.858	-0.556	GW03	15		N
GW05	CasaYbl_GulfBeachUpstrm	2/20/2015	26.423039386	-82.071460977	1.92	-0.35		27		N
GW06	CasaYbl_GulfBeachDwnstrm	3/23/2015	26.422871491	-82.071412348	2.198	-0.403	GW05	10		N
GW07	WestWind_GulfBeachUpstrm	8/4/2015	26.426675993	-82.101919395	2.136	-0.055		36		N
GW08	WestWind_GulfBeachDwnstrm	2/17/2015	26.426534001	-82.101952632	2.3	-0.368	GW07	20		N
GW09	BeachAcess7_GulfBeachUpstrm	6/30/2015	26.436499547	-82.125619024	3.776	-0.5085		67		N
GW10	BeachAcess7_GulfBchDwnstrm	2/17/2015	26.436141265	-82.125712993	2.244	-0.352	GW09	30		N
GW11	BowmansBeach_GulfBeachUpstrm	3/17/2015	26.457072342	-82.153609706	2.293	-0.208		45		N
GW12	BowmansBeach_GulfBeachDwnstrm	10/7/2015	26.456982281	-82.153661153	2.055	-0.076	GW11	35		N
GW13	Sanct1EstUpstrm	3/6/2015	26.484590000	-82.168730000	1.832	-0.472				Y
GW14	SanctEstDwnstrm	3/6/2015	26.485040000	-82.167500000	1.874	-0.578	GW13	290		N
GW17	Sanct3EstUpstrm	3/6/2015	26.492165327	-82.170230392	2.15	-0.144		31		Y
GW18	Sanct3EstDwnstrm	3/6/2015	26.493256254	-82.170255647	1.912	-0.399	GW17	150		N
GW19	LCECEstUpstrm	9/3/2015	26.460090000	-82.146030000	2.012	-0.1605		300	15	N
GW20	LCECEstDwnstrm	6/30/2015	26.460114020	-82.145966465	2.119	-0.5125	GW19	300	5	N
GW21	SanCapGulfPinesUpstrm	3/4/2015	26.452569697	-82.133188021	2.122	-0.693	GW44	260		N
GW22	SanCapGulfPinesDwnstrm	3/4/2015	26.452949290	-82.132435566	1.906	-0.691	GW21	200		N
GW23	RecCenterBallFld_Upstrm	2/18/2015	26.445935903	-82.114233559	1.518	-0.453		300		Y
GW24	RecCenterBallFld_Dwnstrm	2/19/2015	26.447232547	-82.114233446	2.21	-0.926	GW23	184		Y
GW25	Gumbo1Upstrm	2/26/2015	26.443600000	-82.067850000	2.443	-0.872		600	116	N
GW26	Gumbo1Dwnstrm	2/26/2015	26.443580000	-82.068080000	2.033	-0.953	GW25	580		N
GW27	DunesWest_Upstrm	2/24/2015	26.454817467	-82.052670620	1.517	-0.467		9	27	Y
GW28	DunesWest_Dwnstrm	2/24/2015	26.454960000	-82.052850000	1.7	-0.3885	GW27	6	23	Y
GW29	DunesNorthUpstrm	8/28/2015	26.458080000	-82.048100000	2.066	-0.765			110	Y
GW30	DunesNorthDownstream	2/24/2015	26.460242202	-82.048297853	2.611	-1.682	GW29	5	18	Y
GW31	BayDrUpstrm	2/19/2015	26.461134798	-82.048140018	2.336	-1.325	GW30	120		N
GW32	BayDrDwnstrm	2/19/2015	26.461871019	-82.048271436	2.907	-1.78	GW31	60		N
GW33	BaileyRdEstuary_Upstrm	2/23/2015	26.453958742	-82.038161790	1.579	-0.175		74		N
GW34	BaileyRdEstuary_Dwnstrm	2/23/2015	26.454587444	-82.038077228	1.872	-0.733	GW33	5		N
GW35	WWTP_PndEast_Upstrm	2/25/2015	26.448012101	-82.044284241	2.278	-0.693			36	N
GW36	WWTP_PndEast_Dwnstrm	2/25/2015	26.450244488	-82.040334765	1.379	-0.34	GW35/38/42			N
GW37	WWTP_PndWest_Upstrm	2/25/2015	26.447664433	-82.046096338	1.757	-0.177			32	N
GW38	WWTP_PndWest_Dwnstrm	2/25/2015	26.445670000	-82.050990000	2.477	-0.6655	GW37/42		16	N
GW39	SanibelGC_Upstrm	2/23/2015	26.441180781	-82.049638456	1.474	-0.388	GW41		50	Y
GW40	SanibelGC_Dwnstrm	2/23/2015	26.441764302	-82.049663151	1.48	-0.187	GW39		10	Y
GW41	NrPanamaTransct	2/25/2015	26.432956165	-82.051155652	1.86	0.057	GW03		60	Y
GW42	BaileyHomestead_Tansct	2/25/2015	26.444458966	-82.050130170	2.108	-0.4595	GW40		60	Y
GW43	SCCFGulfRidgeIslandWaterWell	3/1/2012	26.459802650	-82.146440790	1.973	-0.609	GW46			N
GW44	SCCFGulfRidgeLiftStation	3/1/2012	26.456085217	-82.143085979	2.094	-0.225				N
GW45	SCCFWestSanibelRiverPreserveEastofRueMar	3/1/2012	26.453308500	-82.136951782	1.88	-0.555				N
GW46	Reference SCCF Preserve Haas Pond	4/7/2015	26.449595538	-82.129679709	2.347	-0.563			14	N
GW47	Casa Ybel just northwest of Sanibel Slough	7/15/2015	26.438252570	-82.058353400	1.479	0			92	N
GW48	Casa Ybel just northwest of Sanibel Slough	10/7/2015	26.437680179	-82.058309865	1.716	-0.374	GW47		28	N
GW49	End of Buttonwood Upstream	7/15/2015	26.447138952	-82.022208935	1.382	0.0205		41		N
GW50	End of Buttonwood on Beach	11/5/2015	26.446897200	-82.022049910	1.568	0.4215	GW49	11		N
GW51	Rabbit road just north of Sanibel Slough Downstream	7/21/2015	26.438344000	-82.108000000	2.14	1.189			51	N
GW52	Rabbit road just north of Sanibel Slough Upstream we	7/21/2015	26.437720010	-82.108026300	2.072	0.958	GW51		5	N

Figure 2. Typical installed well with locking cap and identification sticker.

Table 2. Sampling schedule determined before study initiated to allow wet and dry season comparison.

Site	Group	DrySeason WetPeriod	DrySeason DryPeriod	WetSeason WetPeriod	WetSeason DryPeriod
GW01	a	3/24/2015	12/3/2015	7/30/2015	10/15/2015
GW02	a				
GW03	b	4/29/2015	4/13/2015	7/30/2015	11/4/2015
GW04	b				
GW05	c	3/24/2015	12/3/2015	7/30/2015	10/15/2015
GW06	c				
GW07	d	3/24/2015	12/3/2015	7/30/2015	10/15/2015
GW08	d				
GW09	e	3/24/2015	12/3/2015	7/30/2015	10/15/2015
GW10	e				
GW11	f	3/24/2015	12/3/2015	7/30/2015	10/15/2015
GW12	f				
GW13	g	4/29/2015	4/13/2015	8/17/2015	11/4/2015
GW14	g				
GW17	h	4/29/2015	4/13/2015	8/17/2015	11/4/2015
GW18	h				
GW19	i		12/3/2015	8/17/2015	10/15/2015
GW20	i	3/24/2015			
GW21	j		12/3/2015	8/17/2015	10/15/2015
GW22	j	3/24/2015			
GW23	k	3/24/2015	12/3/2015	8/17/2015	10/15/2015
GW24	k				
GW25	l		12/3/2015	7/30/2015	10/15/2015
GW26	l	3/24/2015			
GW27	m	4/29/2015	4/13/2015	7/30/2015	11/4/2015
GW28	m				
GW29	n		12/3/2015		10/15/2015
GW30	n	3/24/2015		8/17/2015	
GW31	n				
GW32	n	3/24/2015		8/17/2015	
GW33	o	3/24/2015	12/3/2015	7/30/2015	10/15/2015
GW34	o				
GW35	p	4/29/2015	4/13/2015		11/4/2015
GW36	p	4/29/2015	4/13/2015		
GW37	p	4/29/2015	4/13/2015	8/17/2015	11/4/2015
GW38	p	4/29/2015	4/13/2015	8/17/2015	
GW39	q				
GW40	q	4/29/2015	4/13/2015	7/30/2015	11/4/2015
GW41	b	4/29/2015	4/13/2015	7/30/2015	11/4/2015
GW42	b	4/29/2015	4/13/2015	8/17/2015	
GW43	i	4/29/2015	4/13/2015		11/4/2015
GW44					
GW45	j	4/29/2015	4/13/2015		
GW46	j	4/29/2015	4/13/2015		
GW47					
GW48		11/23/2015	12/3/2015	7/30/2015	11/4/2015
GW49		11/23/2015	12/3/2015	7/30/2015	11/4/2015
GW50					
GW51					
GW52		11/23/2015	12/3/2015	7/30/2015	11/4/2015

Figure 3-5. Sampling groundwater using tubing pump. Installing Onset data logger in well. Downloading data from logger for transfer to office computer.

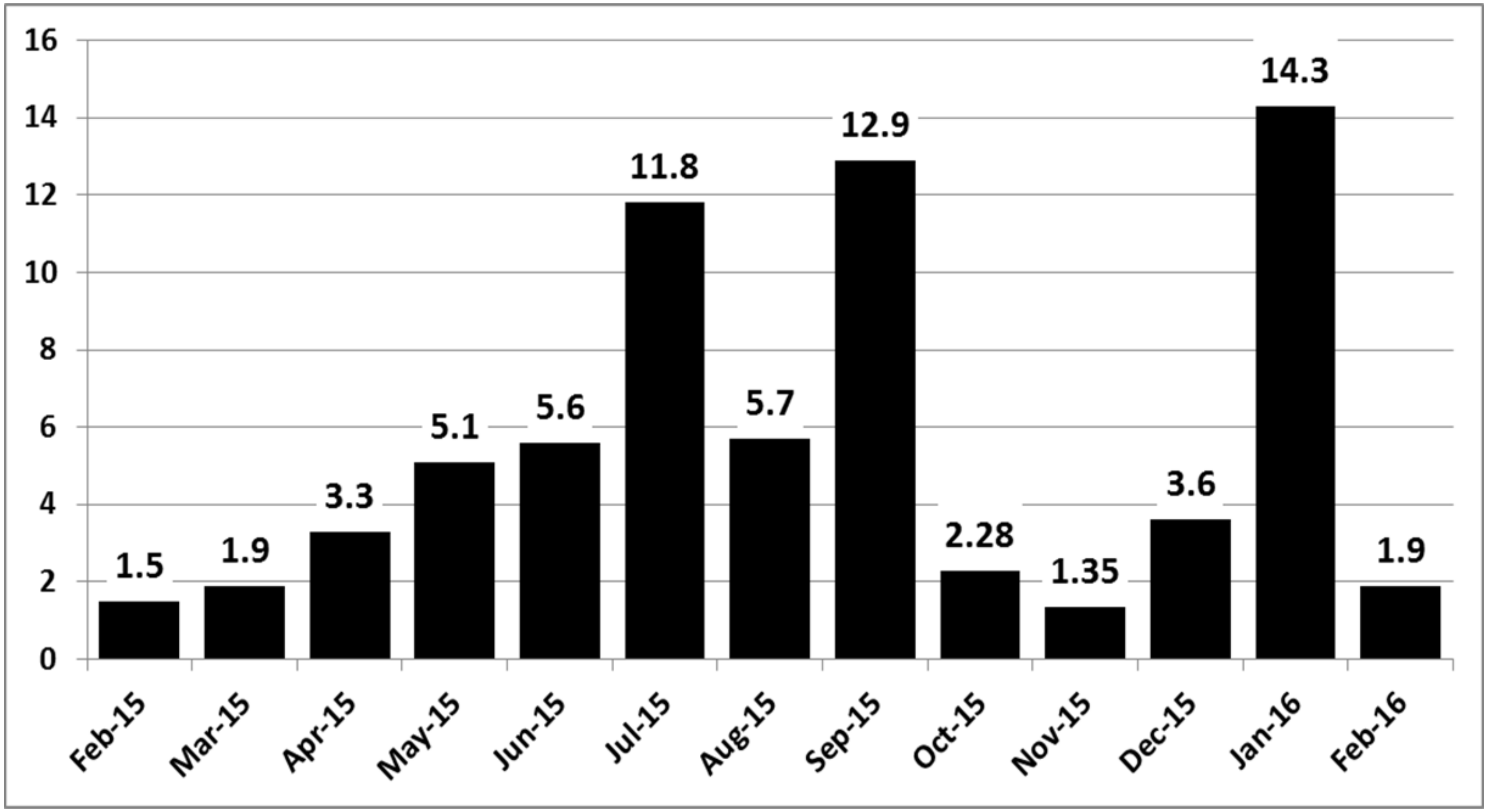

Figure 6. Rainfall data used for this study. Taken from real time weather station data at SCCF installations at The Dunes, Tarpon Bay Weir and SCCF Marine Lab. Rainfall volumes shown in inches (y axis).

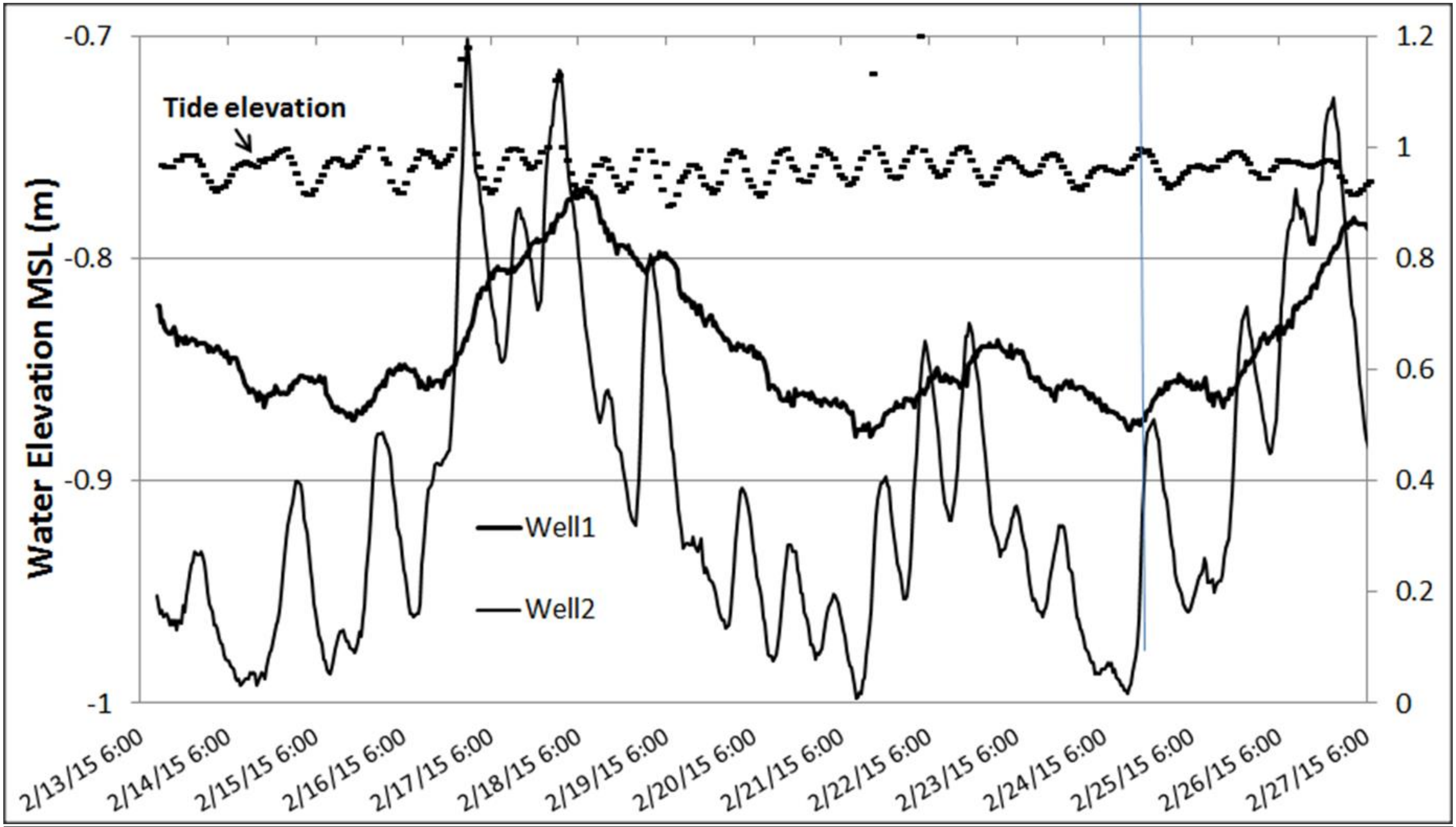

Figure 7. Tidal influence on Gulf shore well groundwater level. Tide elevation relative to MSL plotted on secondary y axis.

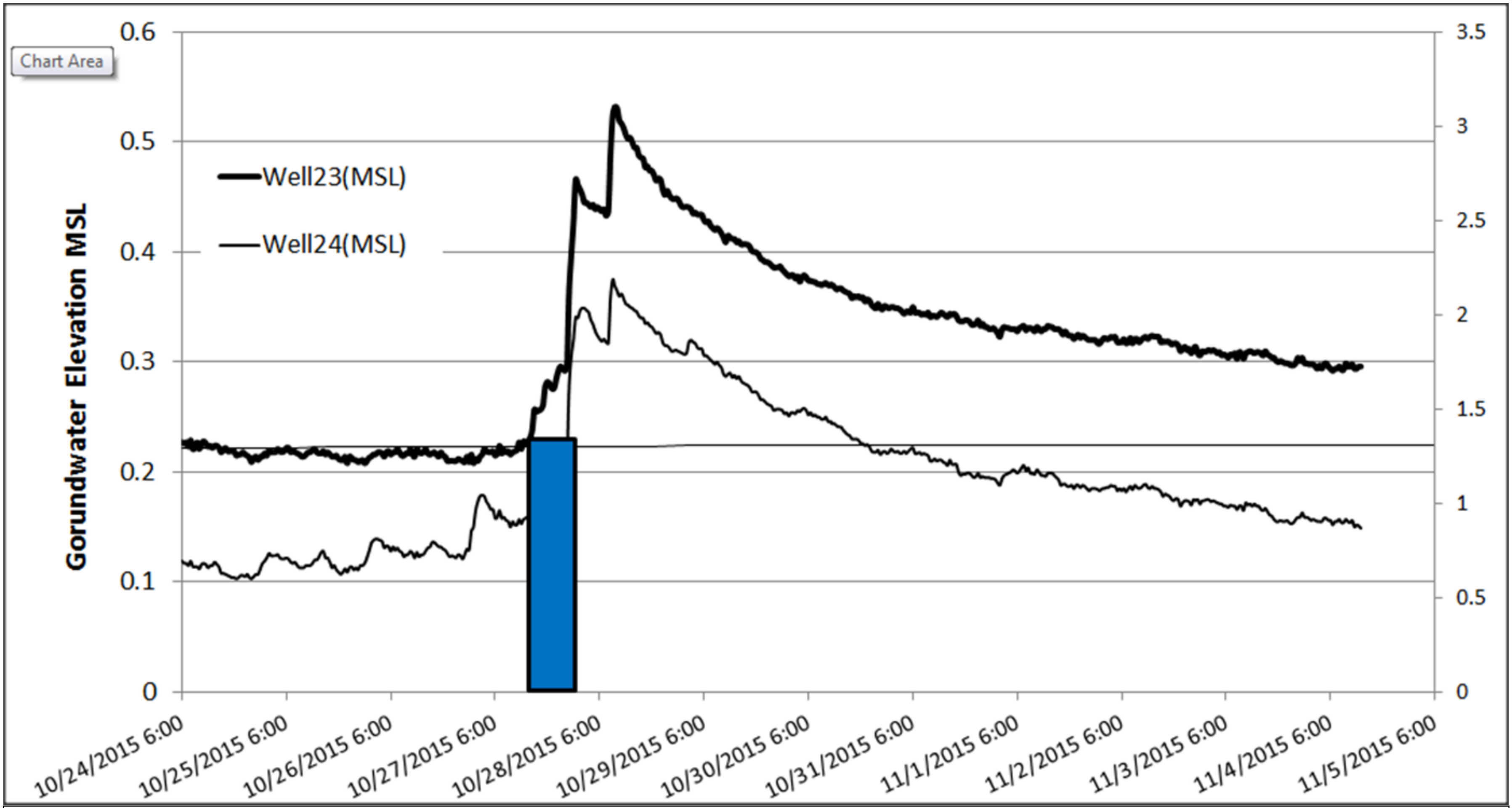

Figure 8. Typical rain influence on groundwater level measured in monitoring wells. Rain event is shown with blue column.

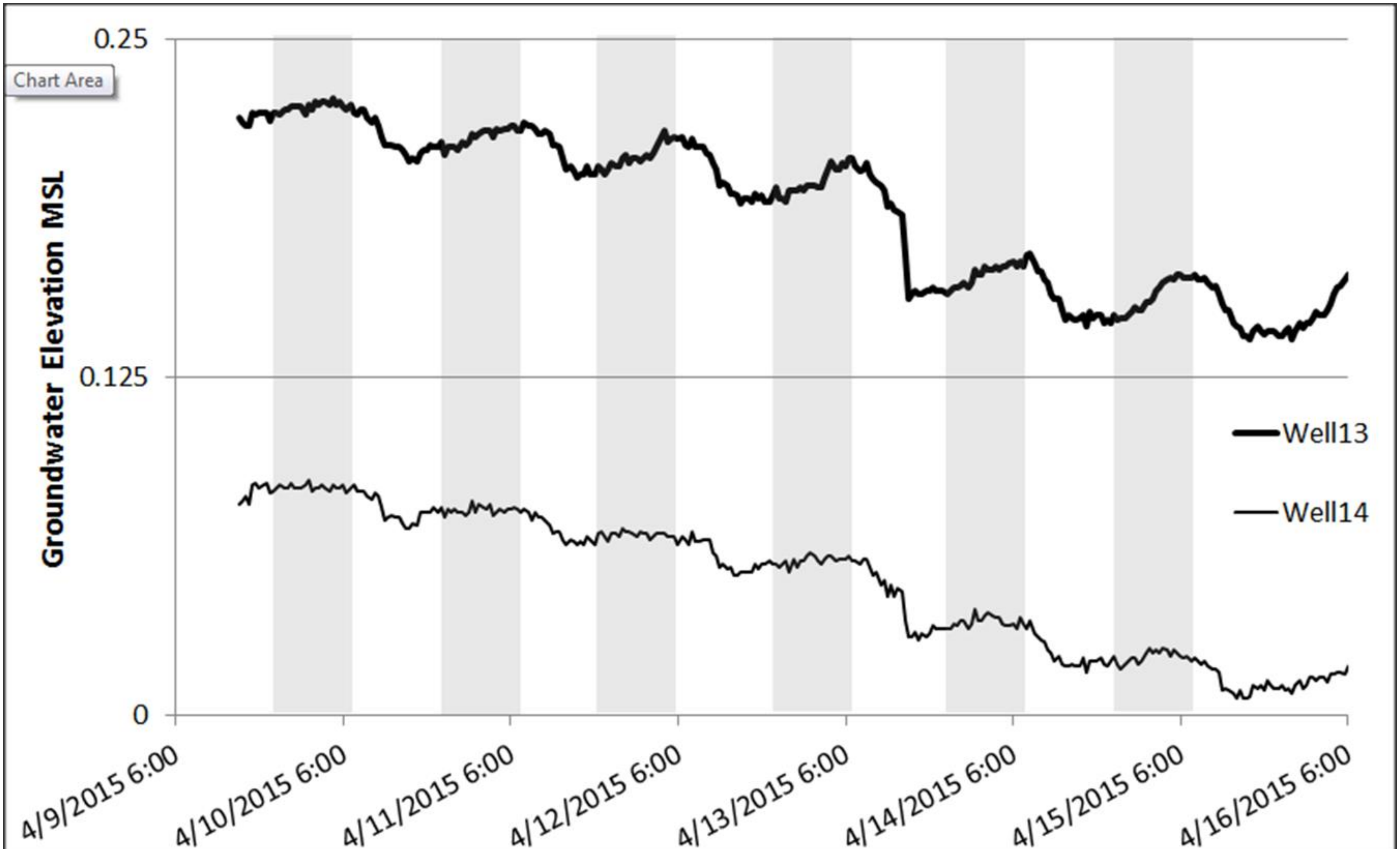

Figure 9. Evapotranspiration influence on groundwater level. Diel cycle evident with groundwater levels lowered by greater daytime evapotranspiration and rebounding during lower nighttime (shaded areas) rates.

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Table 3. Estimated groundwater discharge to surface waters adjacent to Sanibel, with comparison to previously developed estimates for stormwater discharges.

Season	Estimated Annual Discharge to Surface Waters		Sanibel IN Load (kg/yr)		Sanibel TN Load (kg/yr)		Sanibel OP Load (kg/yr)		Sanibel TP Load (kg/yr)	
	Surficial Aquifer	Stormwater Runoff	Surficial Aquifer	Stormwater Runoff	Surficial Aquifer	Stormwater Runoff	Surficial Aquifer	Stormwater Runoff	Surficial Aquifer	Stormwater Runoff
Dry	1,463,266	935,446	1392	191	3864	950	428	96	516	171
Wet	3,360,660	4,673,054	2448	1358	8325	4705	561	901	654	1460
Total	**4,823,926**	**5,608,500**	**3,840**	**1,549**	**12,188**	**5,655**	**989**	**997**	**1,170**	**1,631**

Table 4. Groundwater discharge calculations by site and receiving waterbody derived using Darcy's law.

Site	Receiving Waterbody	Distance Between Sites (km)	Distance for Flow Calc (km)	Dry Season (136 days) Flow Rate (m3/km-day)	Dry Season (136 days) Flow Estimate (m3/day)	Dry Season (136 days) Annual Discharge (m3/yr)	Wet Season (229 days) Flow Rate (m3/km-day)	Wet Season (229 days) Flow Estimate (m3/day)	Wet Season (229 days) Annual Discharge (m3/yr)	Estimated Total Annual (m3)
East End Island	Gulf	0								
GW49	Gulf	1.197	2.2285	446	994	135,172	510	1,136	260,241	395,413
GW01	Gulf	2.063	1.633	1,339	2,187	297,425	1,631	2,663	609,778	907,203
GW03	Gulf	1.203	1.78	1,473	2,623	356,671	1,561	2,778	636,270	992,941
GW05	Gulf	2.357	2.7445	232	636	86,494	839	2,303	527,354	613,847
GW07	Gulf	3.132	2.8745	332	955	129,911	709	2,037	466,549	596,459
GW09	Gulf	2.617	3.121	-184	-575	0	-75	-233	0	0
GW11	Gulf	3.625	6.1555	-61	-375	0	-70	-432	0	0
West End Island	Gulf	4.343								
Total Gulf Discharge				**3,823**	**7,395**	**1,005,672**	**5,249**	**10,918**	**2,500,192**	**3,505,864**
West End Island	Sound	0								
GW17	Sound	1.511	2.13	232	495	67,284	230	490	112,323	179,607
GW13	Sound	1.245	2.42	11	27	3,716	15	37	8,561	12,277
GW19	Sound	3.604	2.62	-2	-4	0	25	65	14,776	14,776
GW21	Sound	1.626	1.80	7	12	1,611	5	8	1,903	3,514
GW23	Sound	1.98	3.38	0	-1	0	11	36	8,239	8,239
GW25	Sound	4.789	3.75	-46	-174	0	-107	-403	0	0
GW27	Sound	2.717	1.85	-201	-372	0	237	439	100,550	100,550
GW30	Sound	981	1.10	4	5	631	8	8	1,915	2,546
GW33	Sound	1.228	3.17	562	1,780	242,032	709	2,246	514,319	756,351
East End Island	Sound	2.555								
Total Sound Discharge				**816**	**2,318**	**315,274**	**1,239**	**3,330**	**762,585**	**1,077,860**
East End Slough	Slough	0								
GW40	Slough	1	3	268	844	114,738	71	225	51,439	166,177
GW48	Slough	4	7	-1	-4	0	-1	-4	0	0
GW52	Slough	10	14	15	203	27,582	15	203	46,443	74,026
West End Slough	Slough	9								
Total Slough Discharge				**283**	**1,046**	**142,320**	**86**	**424**	**97,882**	**240,203**
Total						**1,463,266**			**3,360,660**	**4,823,926**

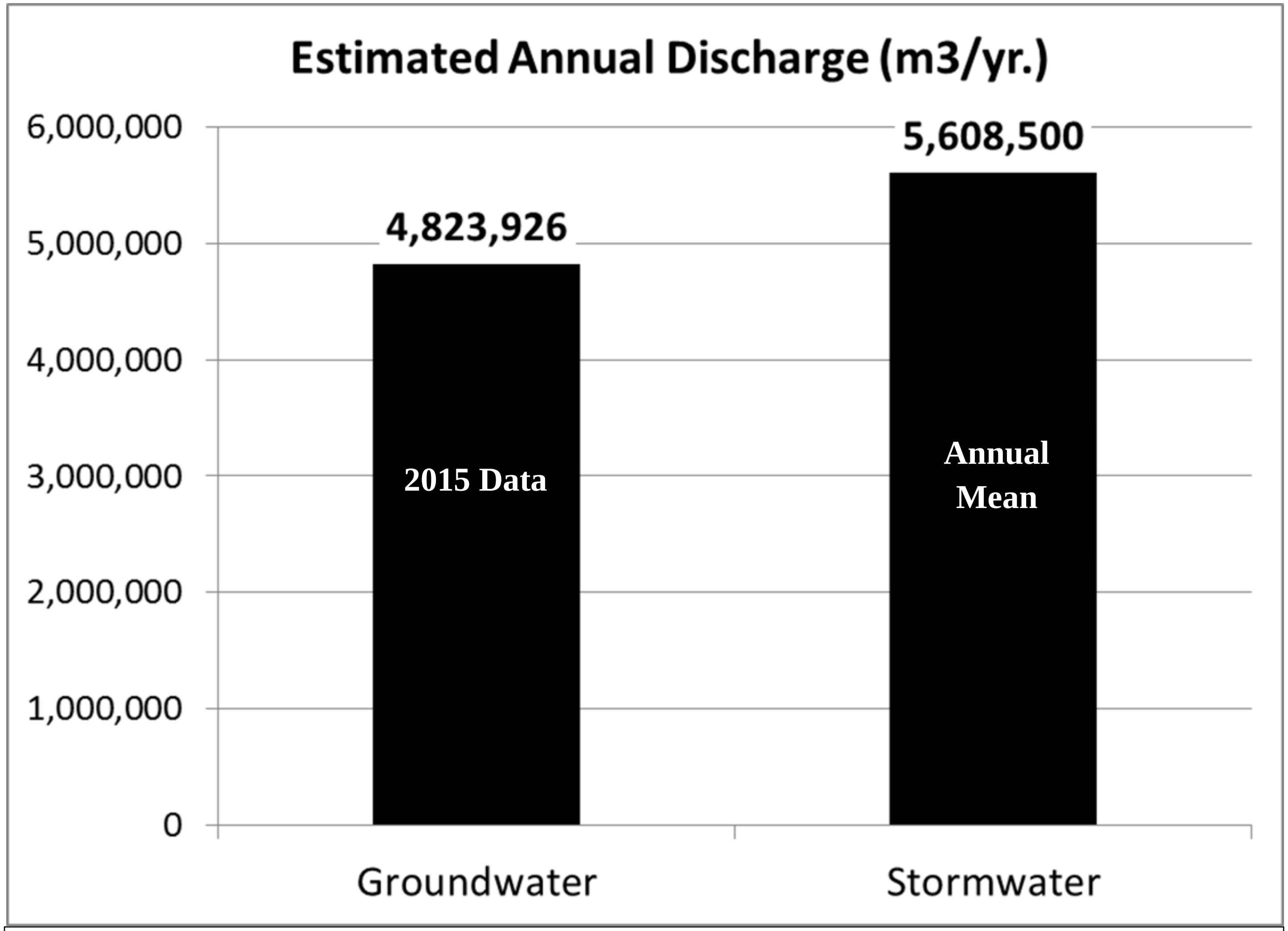

Figure 10. Annual Sanibel groundwater discharge estimates made in this study compared to annual stormwater estimates made in previous study.

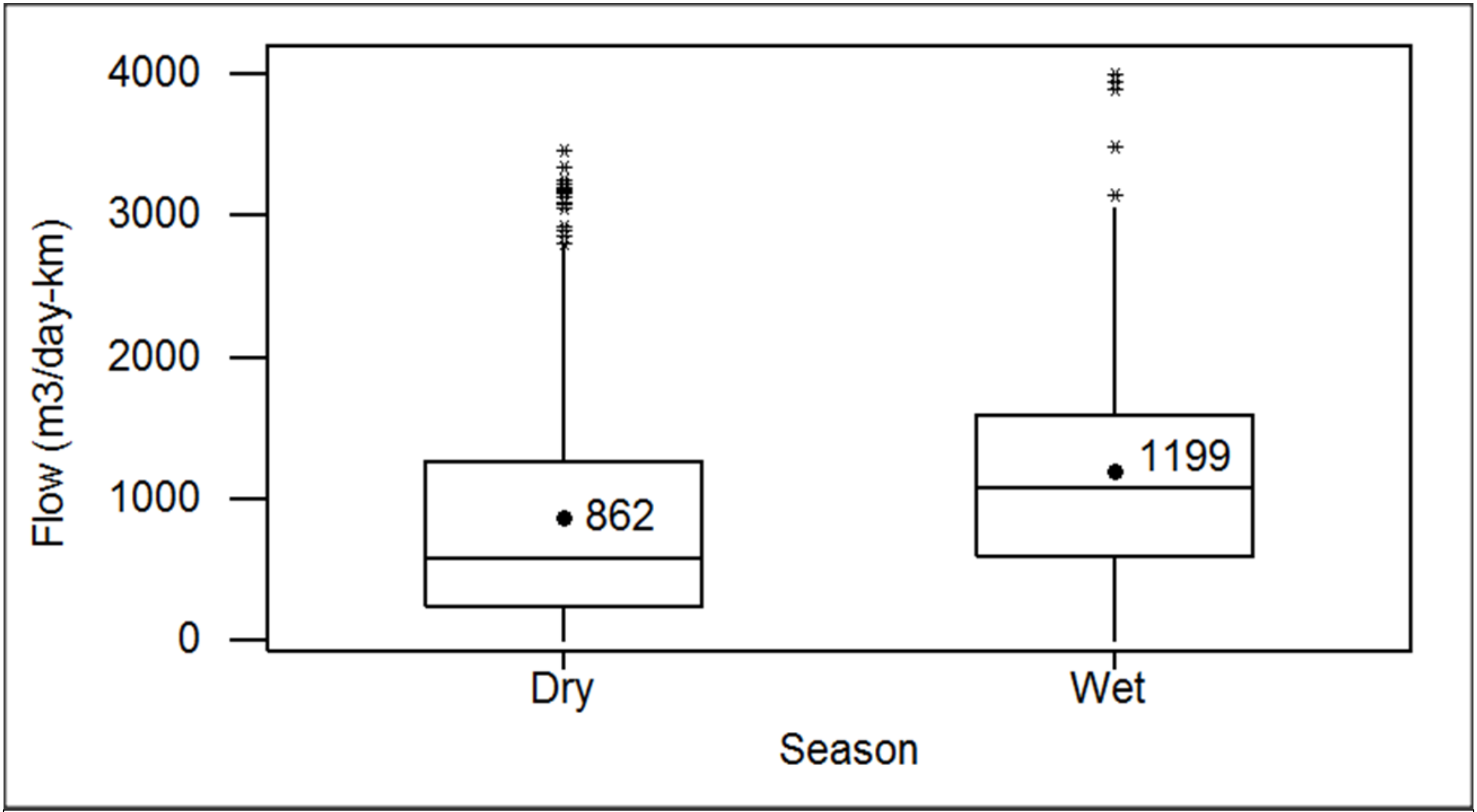

Figure 11. . Mean wet and dry season flow at sites discharging to **Gulf of Mexico**. Wet season flow is significantly greater than dry season (paired t-test, $p< 0.001$, $T = 6.5$)

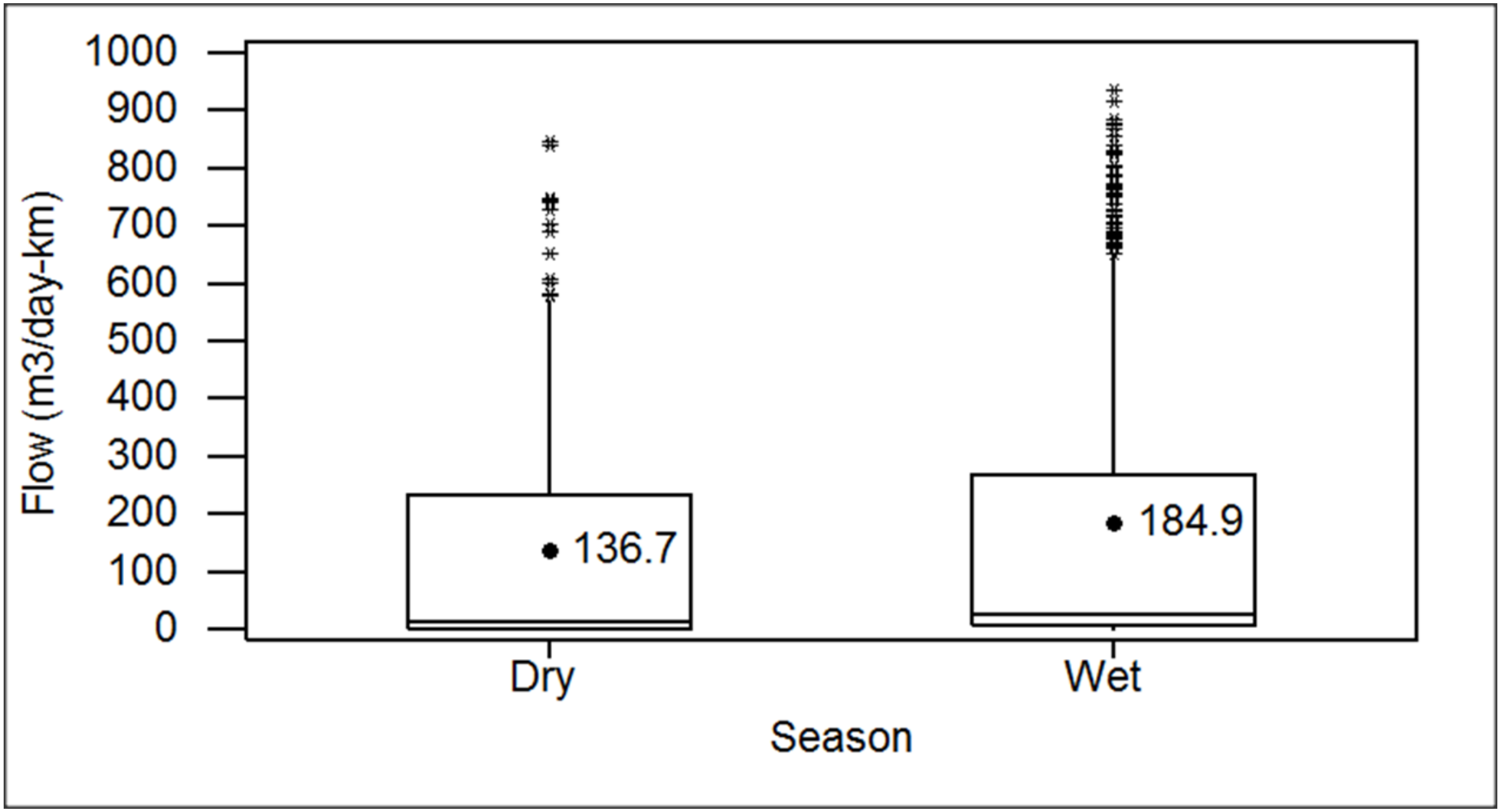

Figure 12. Mean wet and dry season flow at sites discharging to **Pine Island Sound**. Wet season flow is significantly greater than dry season (paired t-test, $p < 0.001$, $T = 13.2$)

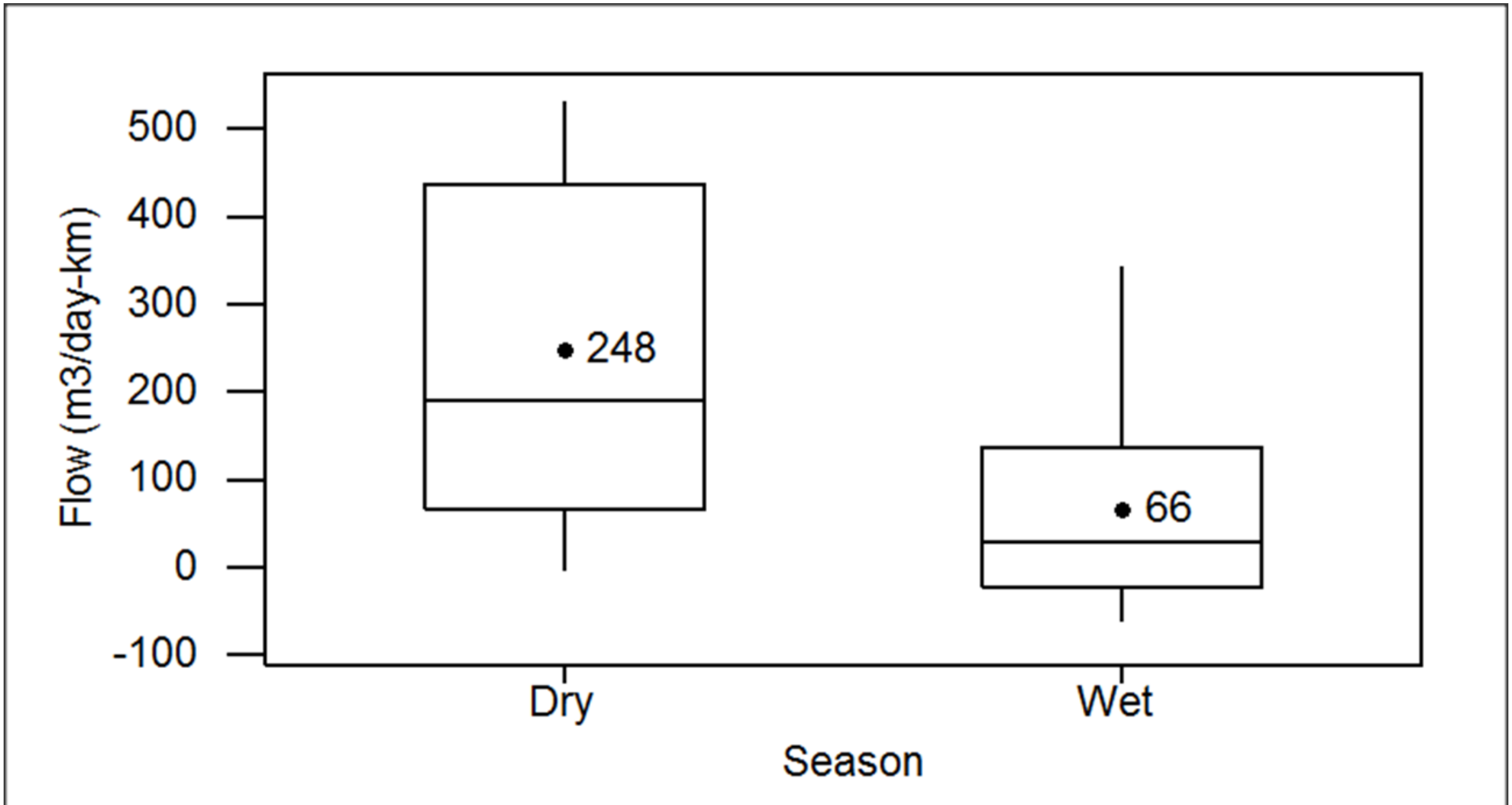

Figure 13. Mean wet and dry season flow at sites discharging to **Sanibel Slough**. Dry season flow is significantly greater than wet season (t-test, $p < 0.001$, $T = 4.1$)

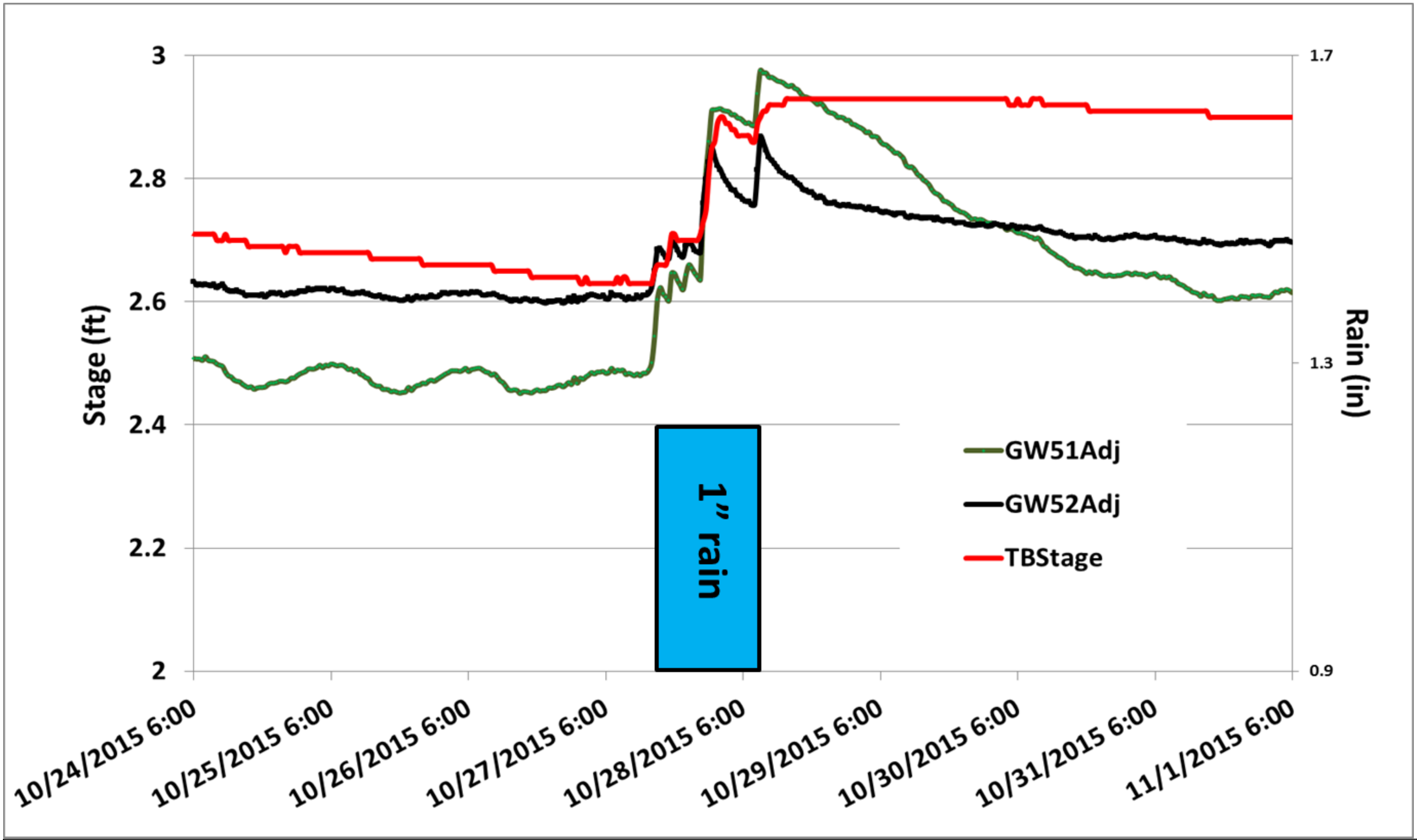

Figure 14. Typical relationship of groundwater level and Sanibel Slough water level showing hydraulic gradient sloping away from slough when water level held artificially high, but reversing after rain event for a short period. GW 52 is adjacent (< 4 meters) Sanibel Slough while GW 52 is 100 meters away.

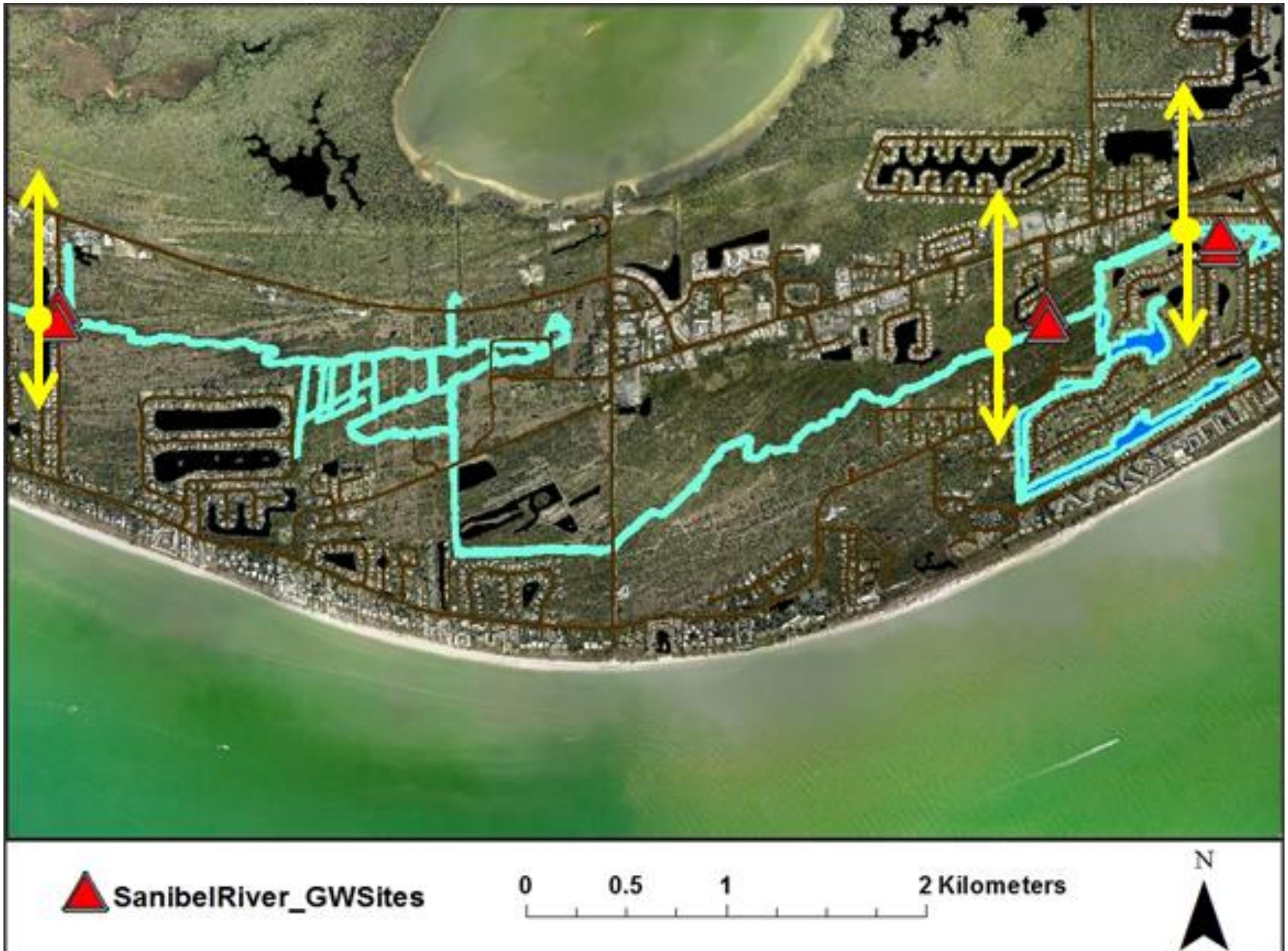

Figure 15. Groundwater flow during high water level in slough.

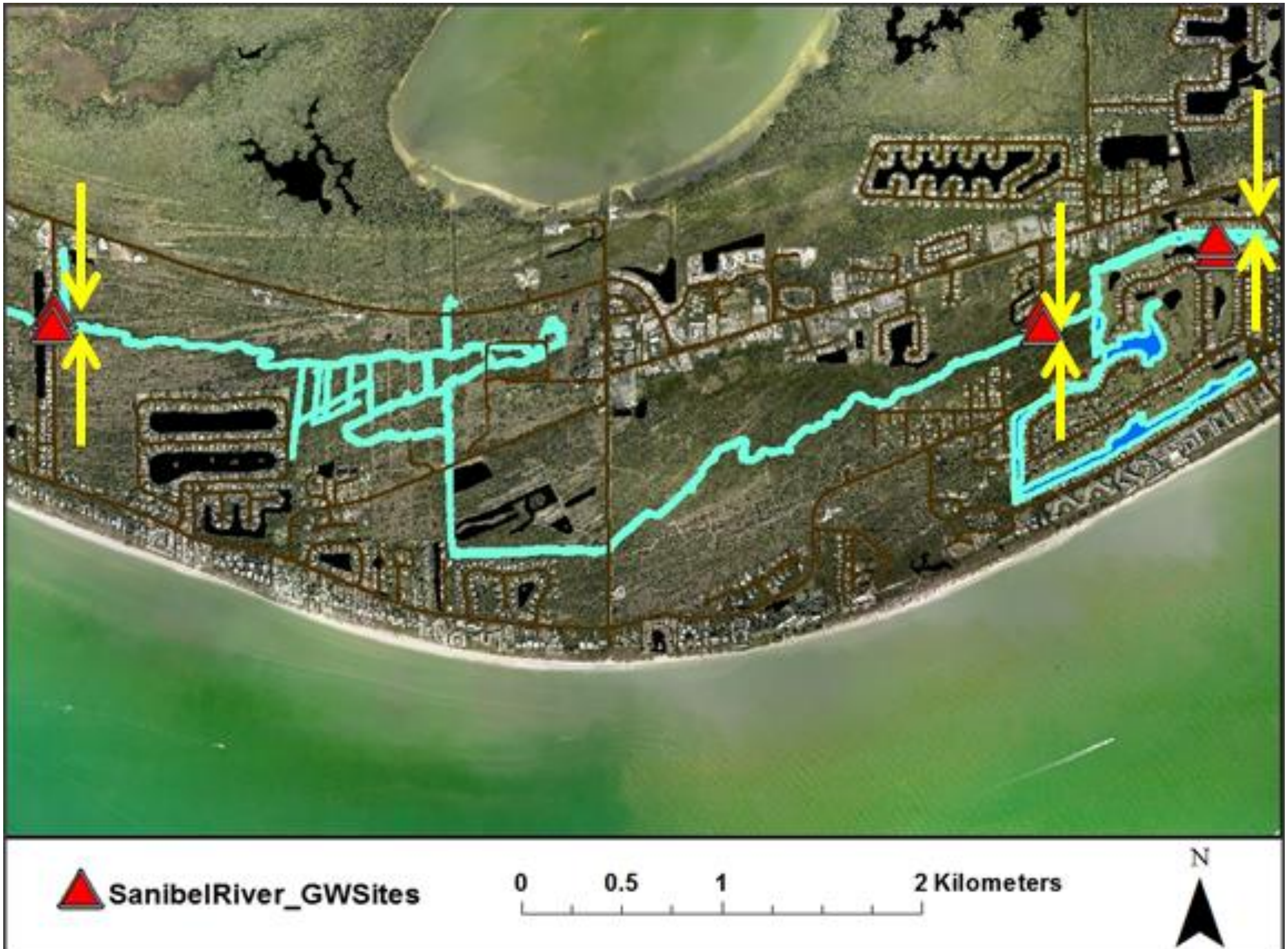

Figure 16. Groundwater flow after rain event or during low water level in the slough.

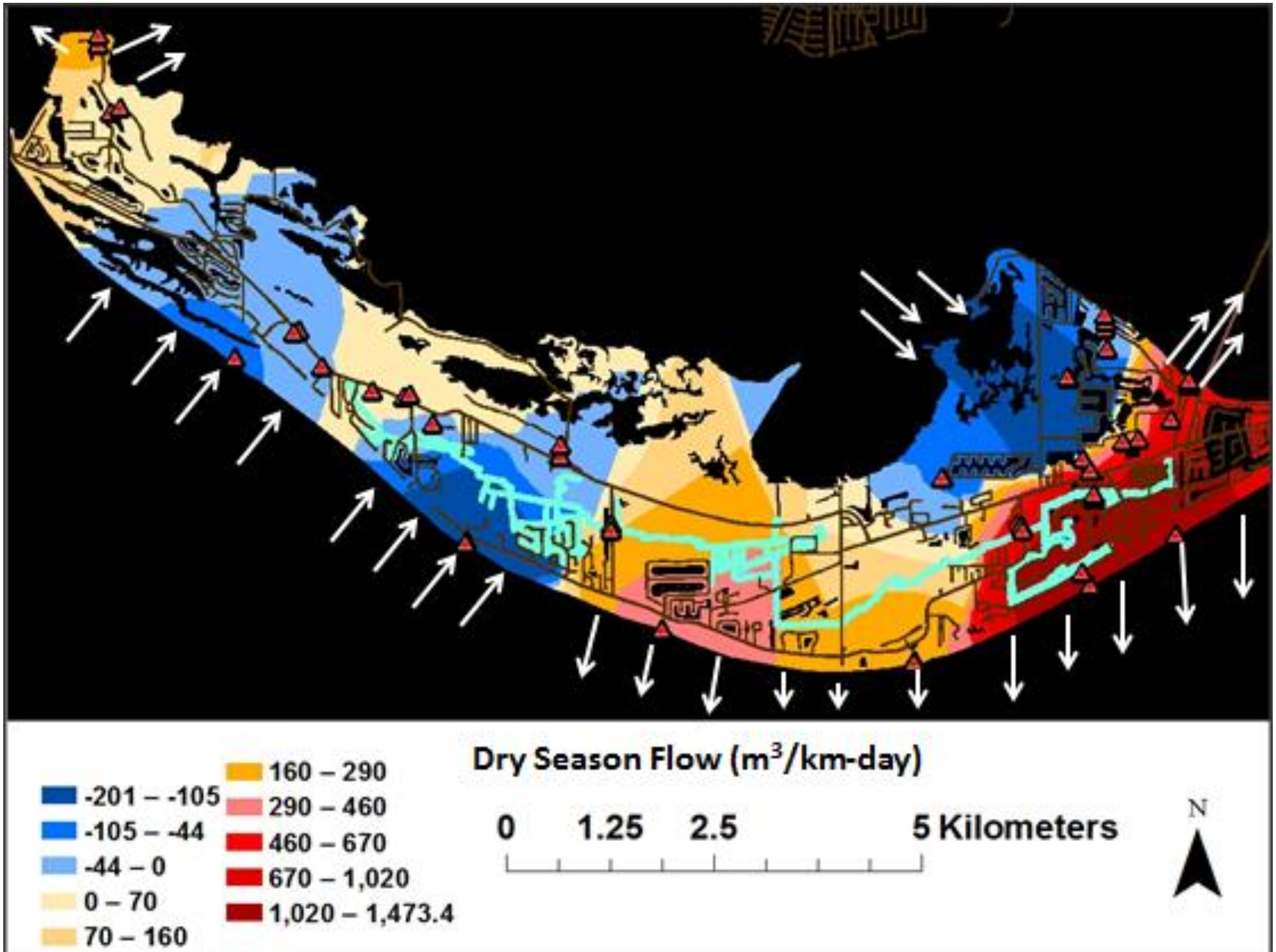

Figure 17: Interpolated map of surficial aquifer groundwater flow during 2015-2016 dry season.

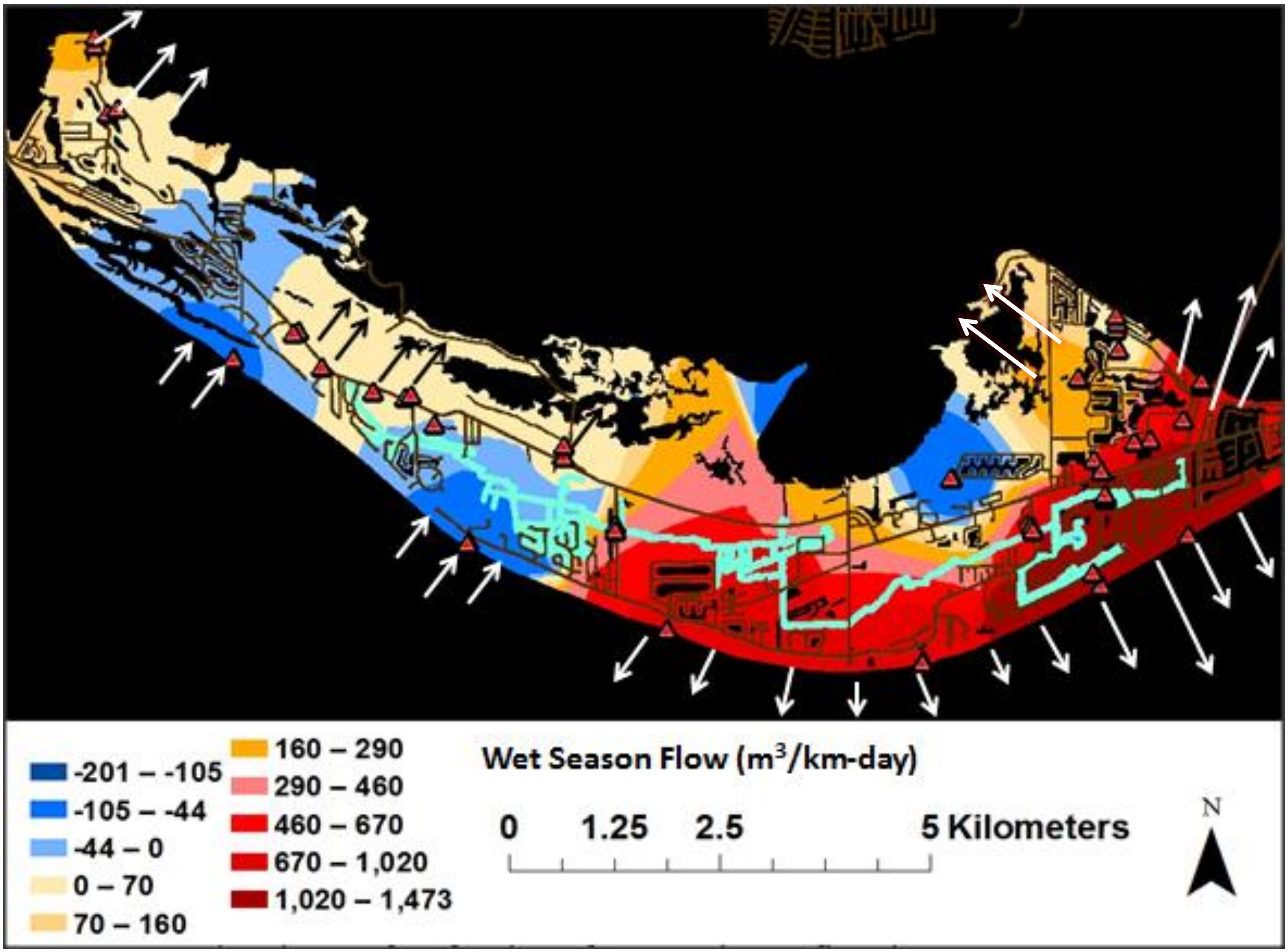

Figure 18: Interpolated map of surficial aquifer groundwater flow during 2015-2016 wet season.

Table 5. Mean groundwater concentration data by monitoring site.

Site	Description	Mean TN (mg/l)	Mean NH3 (mg/l)	Mean NOx (mg/l)	Mean IN (mg/l)	Mean OP (mg/l)	Mean TP (mg/l)	TKN (mg/l)	Salinity (PSU)
GW01	EndofBeachRd	2.0	0.440	0.144	0.58	0.235	0.284	1.81	1.8
GW03	SundialEastCondo	1.2	0.285	0.026	0.31	0.186	0.212	1.19	0.8
GW05	CasaYbel	1.8	0.151	0.030	0.18	0.157	0.188	1.81	2.0
GW07	WestWind	1.2	0.021	0.733	0.75	0.060	0.074	0.51	0.6
GW09	BeachAcess7	0.4	0.048	0.022	0.07	0.034	0.058	0.52	1.9
GW11	BowmansBeach	0.6	0.024	0.164	0.19	0.061	0.068	0.44	20.9
GW13	Sanct1EastUpstrm	3.6	0.610	0.471	1.08	0.124	0.198	3.08	1.0
GW17	Sanct3EastUpstrm	3.4	0.661	0.410	1.07	0.409	0.663	2.96	1.7
GW19	LCECEastUpstrm	2.0	0.555	0.127	0.68	0.219	0.243	1.86	2.5
GW21	SanCapGulfPinesUpstrm	2.8	0.560	0.033	0.59	0.179	0.218	2.75	3.8
GW23	RecCenterBallFld_Upstrm	1.9	0.480	0.135	0.62	0.298	0.341	1.72	6.0
GW25	Gumbo1Upstrm	5.3	1.763	0.089	1.85	0.996	2.542	5.23	18.3
GW27	DunesWest_Upstrm	26.2	20.639	0.223	20.86	0.814	1.120	26.10	5.2
GW29	DunesNorthUpstrm	8.5	3.310	0.319	3.63	0.221	0.270	8.15	2.1
GW30	DunesNorthDownstream	31.9	16.930	0.031	16.96	0.423	0.466	31.93	10.5
GW32	BayDr	1.6	0.353	0.008	0.36	0.105	0.129	1.64	38.9
GW33	BaileyRd	2.9	0.594	0.174	0.77	0.161	0.181	2.73	4.1
GW35	WWTP_PndEast_Upstrm	3.9	3.406	0.010	3.42	0.778	1.023	3.89	1.5
GW36	WWTP_PndEast_Dwnstrm	4.3	1.217	0.210	1.43	1.097	1.200	4.10	3.2
GW37	WWTP_PndWest_Upstrm	1.9	1.048	0.089	1.14	0.776	0.857	1.86	1.4
GW38	WWTP_PndWest_Dwnstrm	3.7	0.627	0.067	0.69	0.574	0.997	3.67	1.9
GW40	SanibelGC	6.7	3.687	0.090	3.78	0.724	0.746	6.60	2.5
GW41	NearPanamaCanal	2.3	0.402	1.238	1.64	0.074	0.110	1.08	1.7
GW42	BaileyHomestead	3.4	0.535	0.012	0.55	0.049	0.107	3.39	4.0
GW43	SCCFGulfRidge	1.6	0.090	0.011	0.10	0.127	0.194	1.56	2.6
GW45	SCCFWestSanibelRiverPreserve	0.7	0.319	0.017	0.34	0.031	0.034	0.73	2.8
GW46	Reference SCCF Preserve Haas Pond	6.8	3.189	0.011	3.20	0.176	0.410	6.80	7.6
GW48	Casa Ybel adjacent Sanibel Slough	4.5	1.932	0.019	1.95	0.123	0.157	4.52	0.8
GW49	End of Buttonwood	2.5	0.153	0.019	0.17	0.208	0.241	2.52	0.4
GW52	Rabbit Road adjacent Sanibel Slough	3.4	0.260	0.123	0.38	0.085	0.097	3.28	0.8

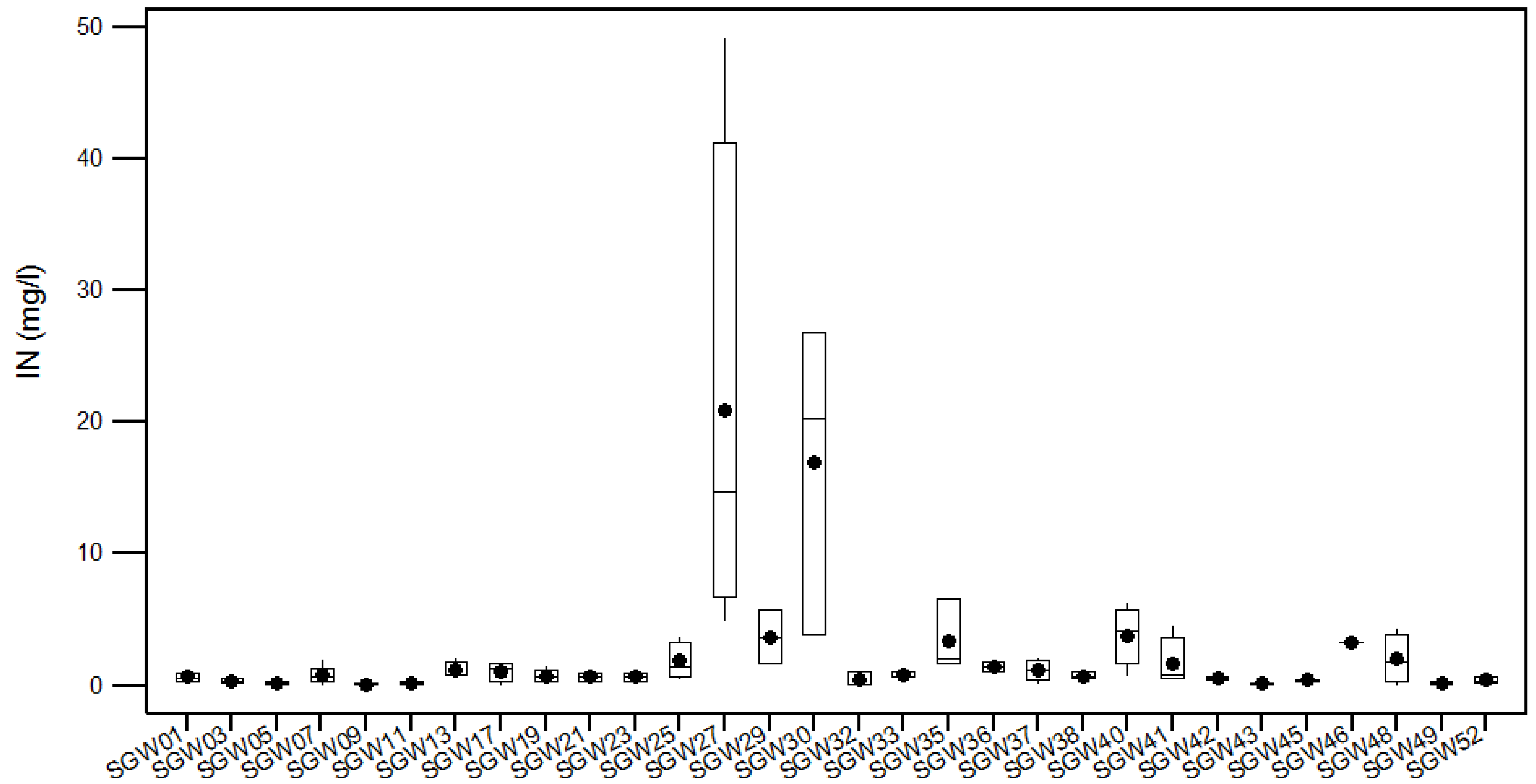

Figure 19. Inorganic nitrogen (IN) by groundwater site. Mean represented by dot, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line.

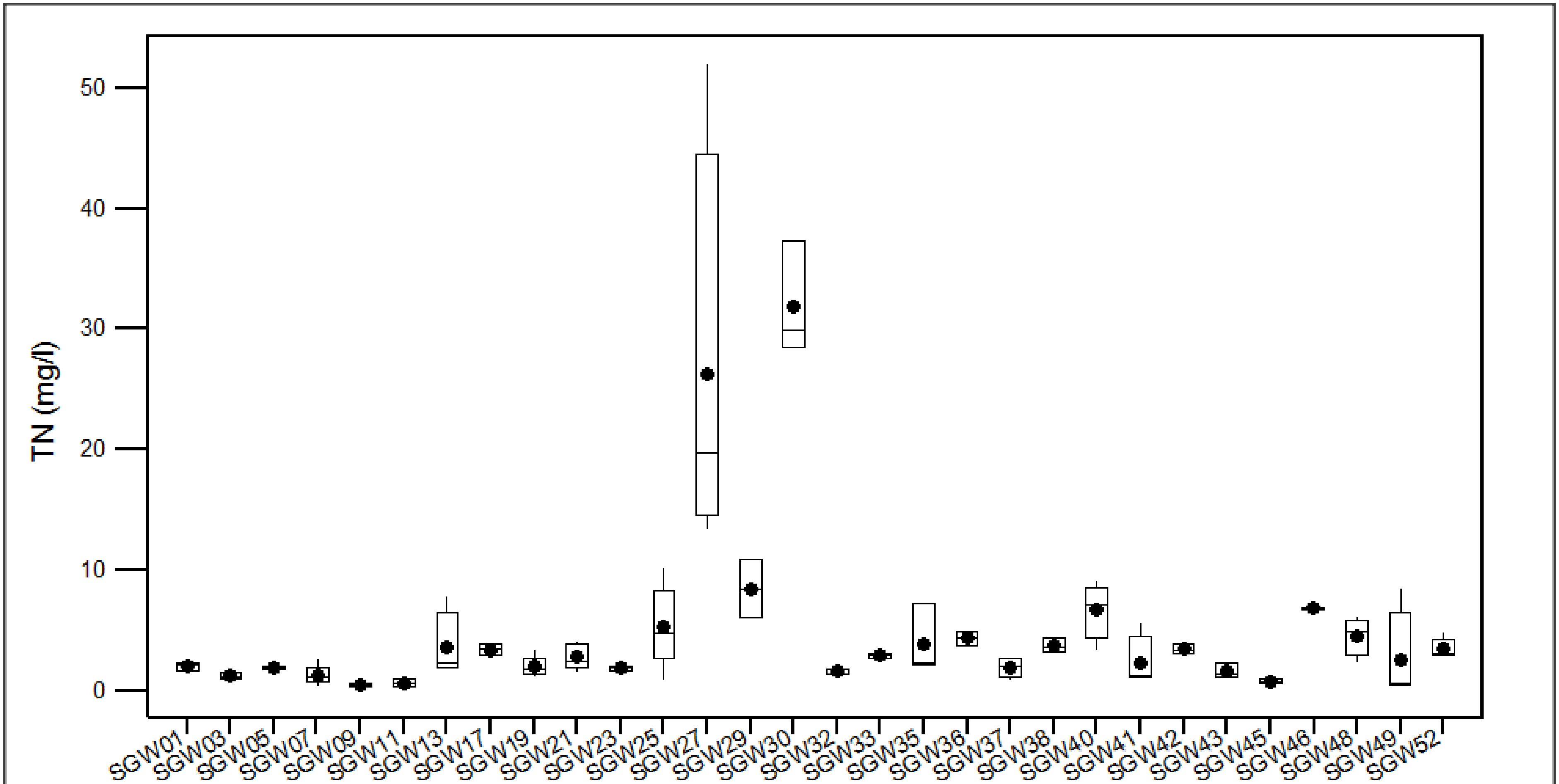

Figure 20. Total nitrogen (TN) by groundwater site. Mean represented by dot, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line.

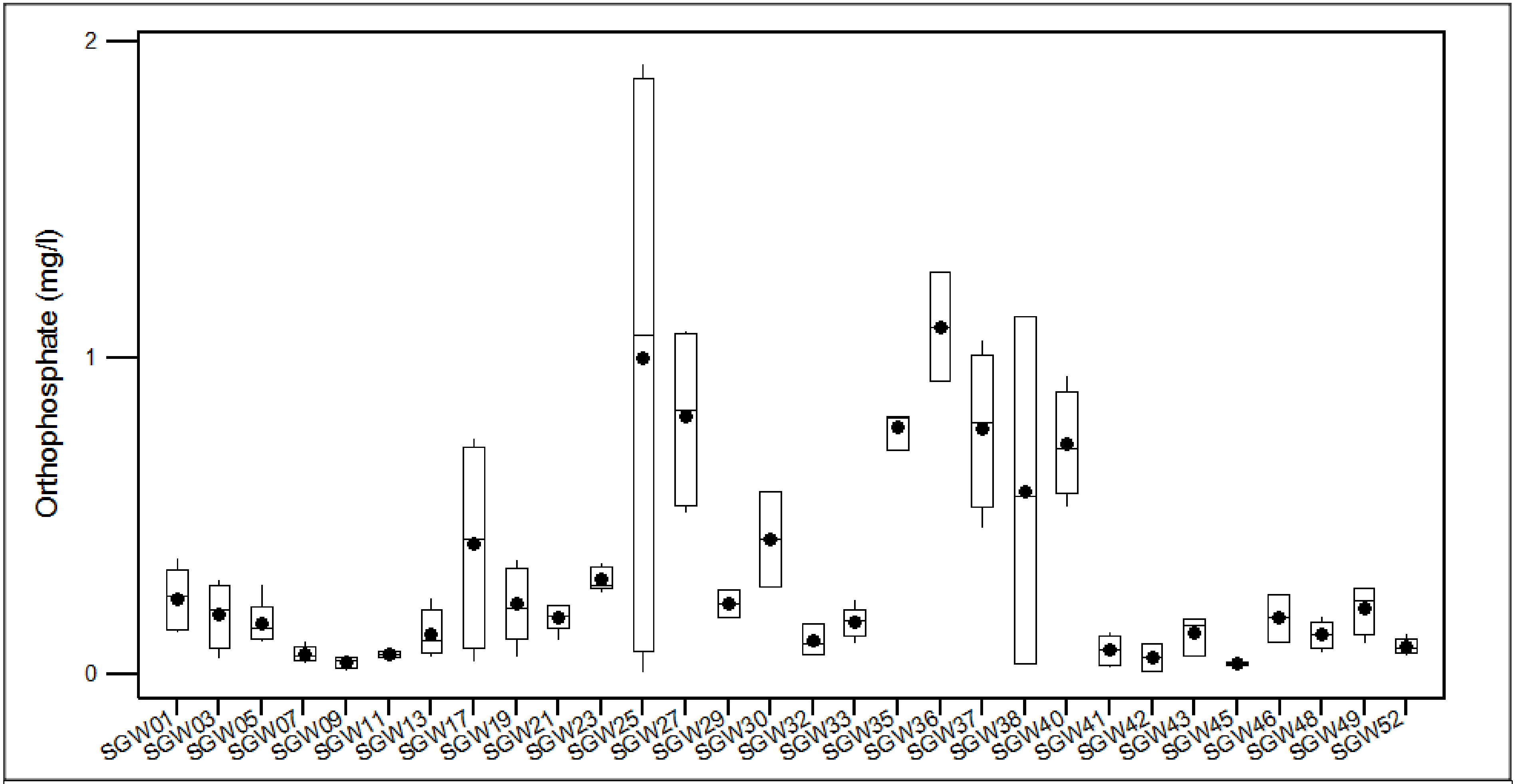

Figure21. Orthophosphate (OP) by groundwater site. Mean represented by dot, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line.

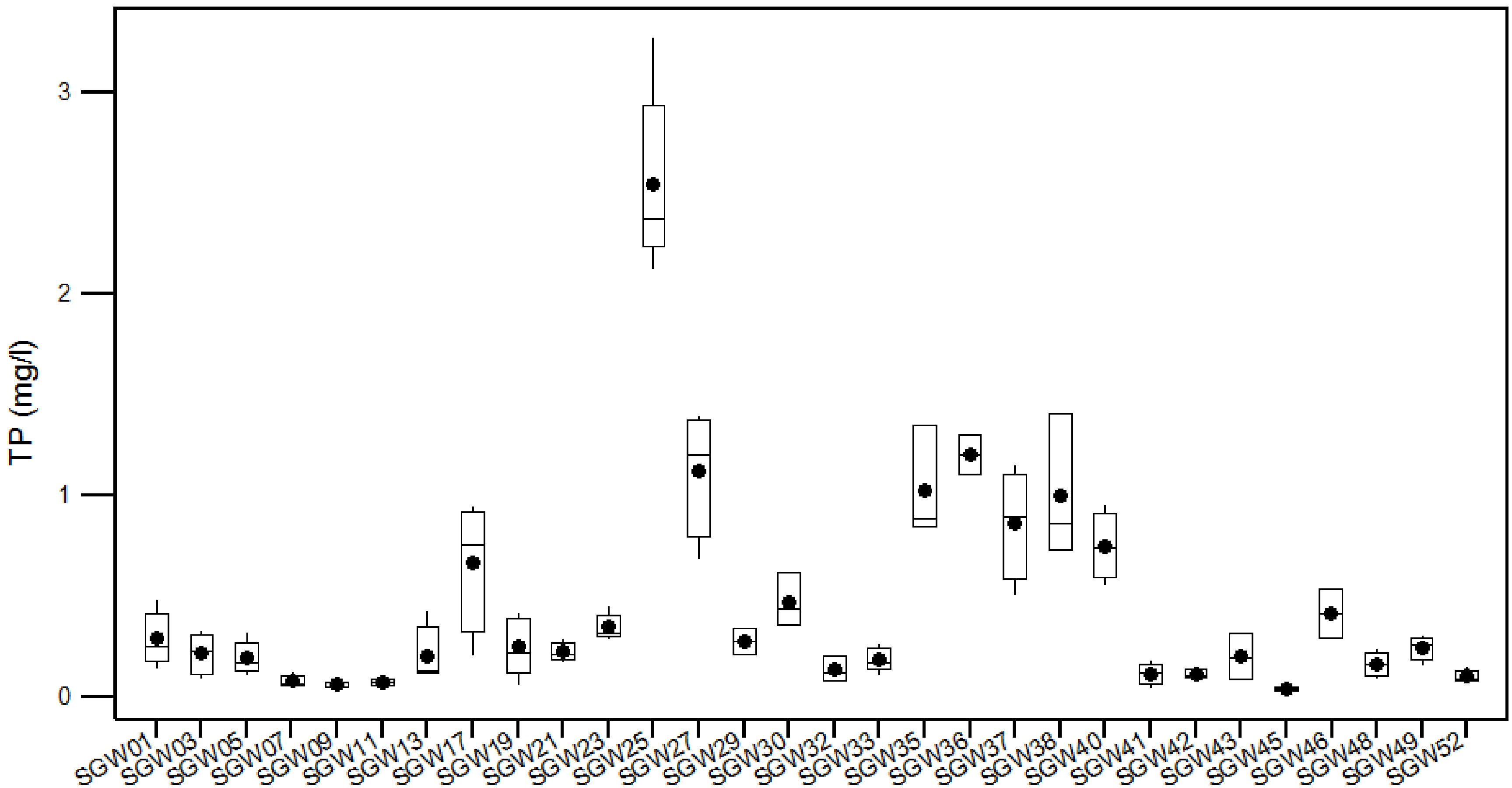

Figure 22. Total phosphorus (TP) by groundwater site. Mean represented by dot, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line.

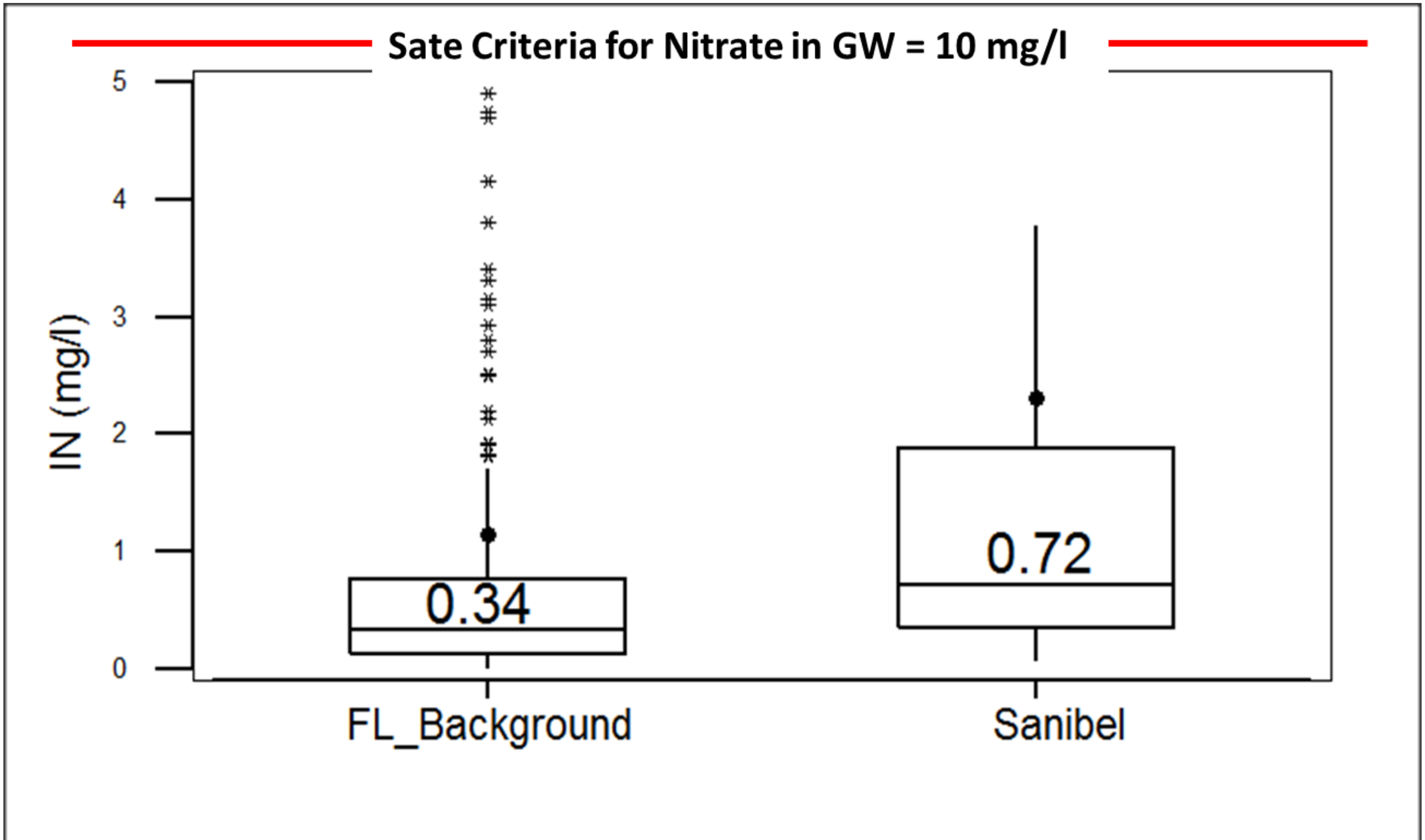

Figure 23. The Florida surficial aquifer background network mean IN concentration for southwest Florida compared to Sanibel mean surficial aquifer IN. eh Florida state drinking water criteria for well water is also shown for comparison purposes by red line.

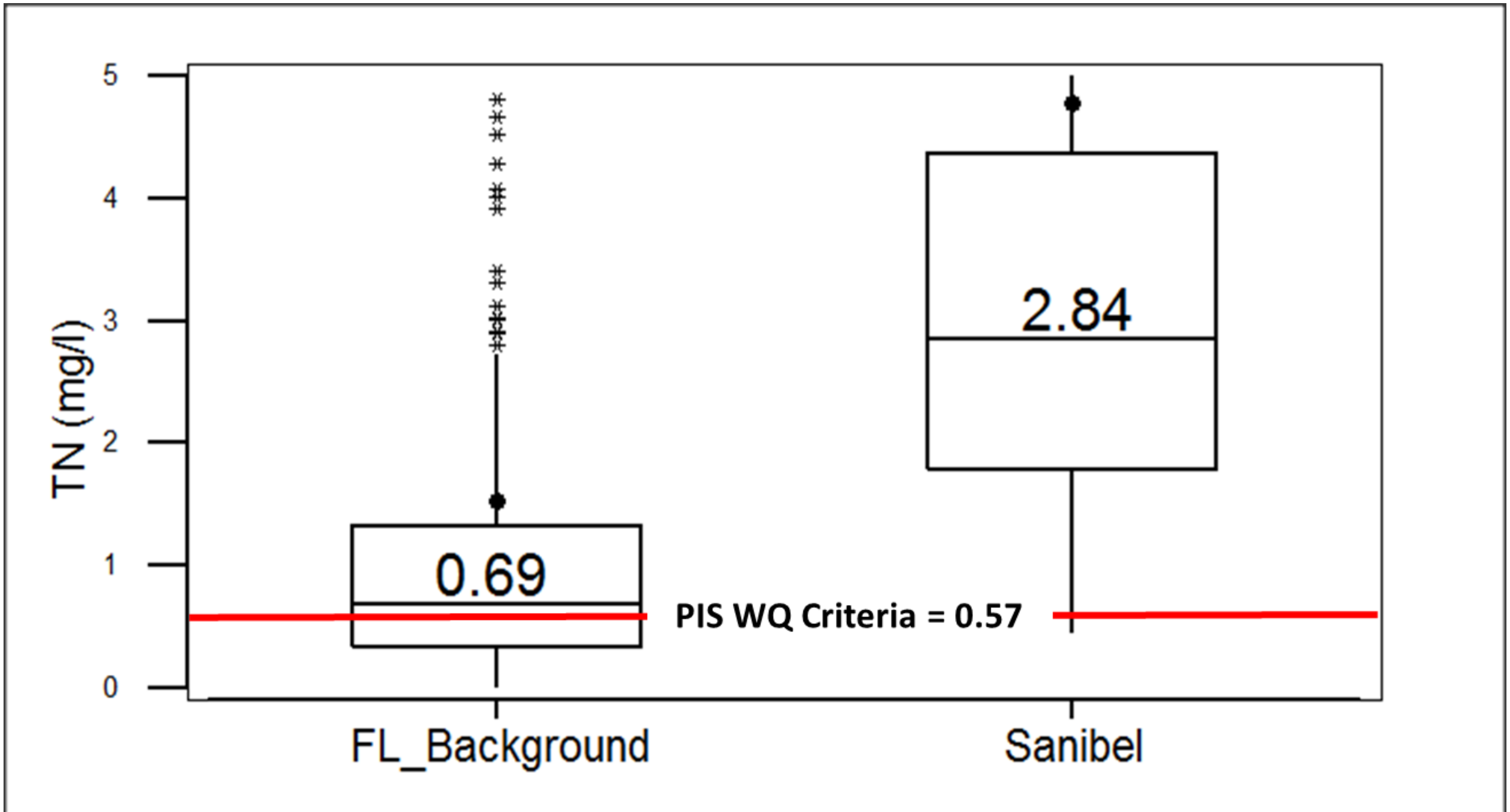

Figure 24. The Florida surficial aquifer background network mean TN concentration for southwest Florida compared to Sanibel mean surficial aquifer TN. The Florida state water quality criteria value for Pine Island Sound is also shown (red line) for comparison.

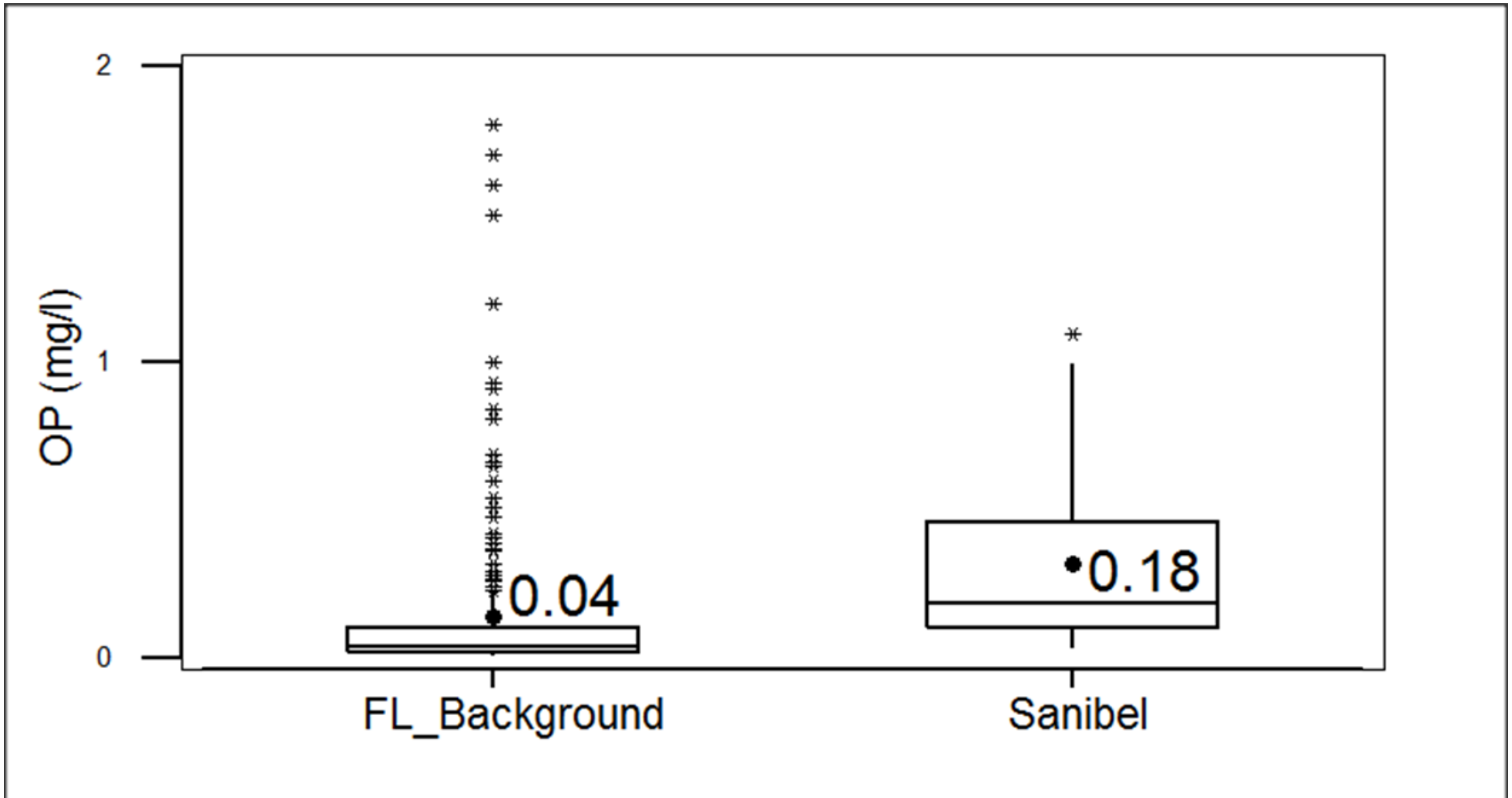

Figure 25. The Florida surficial aquifer background network mean OP concentration for southwest Florida compared to Sanibel mean surficial aquifer OP.

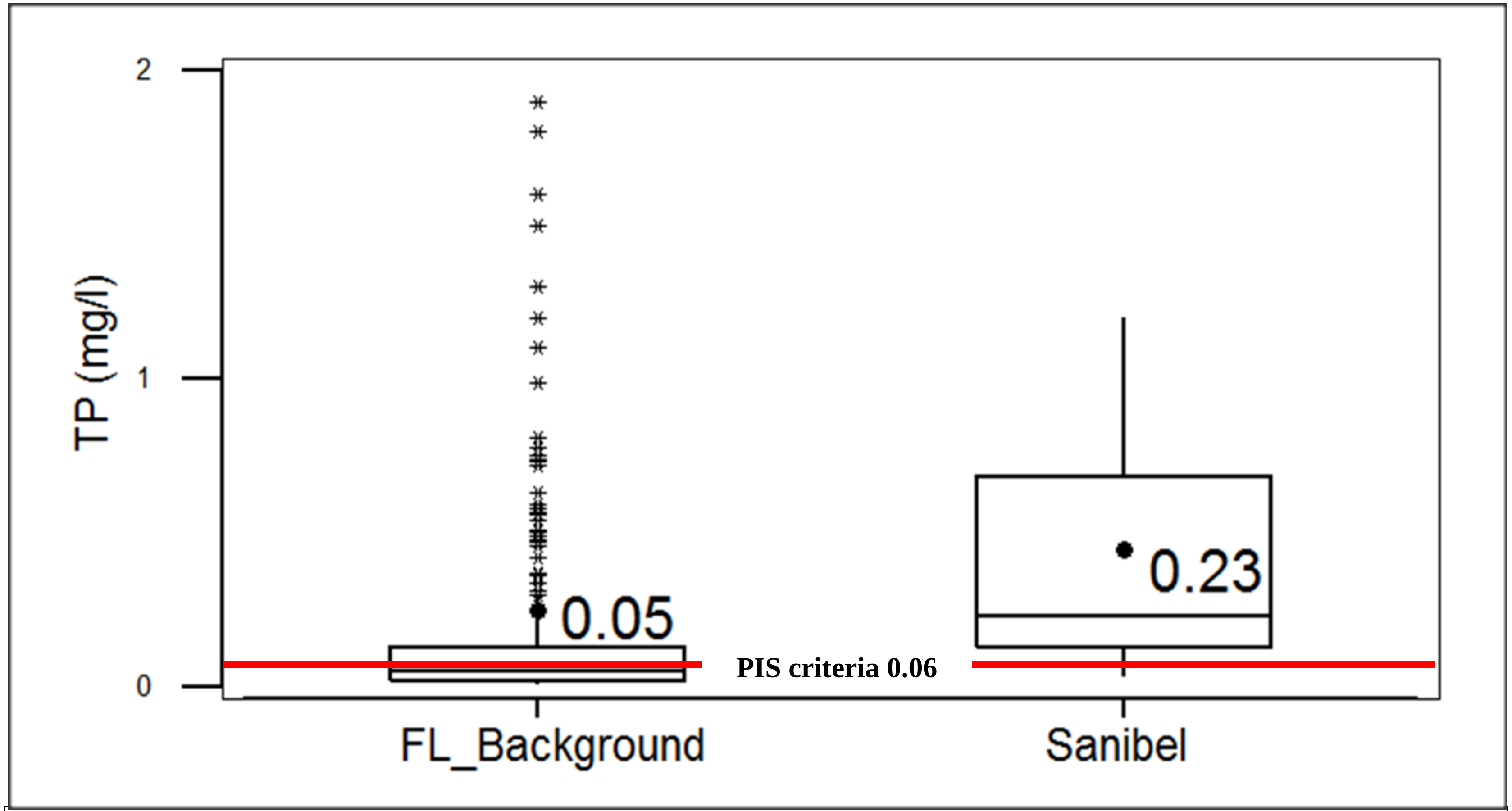

Figure 26. The Florida surficial aquifer background network mean TP concentration for southwest Florida compared to Sanibel mean surficial aquifer TP. The Florida state water quality criteria value for Pine Island Sound is also shown (red line) for comparison.

Table 6. Groundwater site factors for statistical evaluations.

Station	Reclaim/NoRec	Receiving Water	LandClass	Tidal	Evapo	Evapo%	Lake
SGW01	NRC	GM	H	T	1	2	NL
SGW03	RC	GM	H	T	0	0	NL
SGW05	RC	GM	H	T	0	0	NL
SGW07	NRC	GM	H	T	0	0	NL
SGW09	NRC	GM	L	T	0	0	NL
SGW11	NRC	GM	NAT	T	0	0	NL
SGW13	RC	PIS	GC	NT	3	15	NL
SGW17	RC	PIS	GC	T	0	0	NL
SGW19	NRC	PIS	NAT	NT	2	9	L
SGW21	NRC	PIS	NAT	NT	2	7	NL
SGW23	RC	PIS	REC	NT	3	7-17	NL
SGW25	NRC	PIS	WWTP	NT	3	10-15	NL
SGW27	RC	PIS	GC	T	3	10-20	L
SGW29	RC	PIS	GC	T	1	1-5	L
SGW30	RC	PIS	GC	T	0	0	L
SGW32	NRC	PIS	NAT	T	0	0	NL
SGW33	NRC	PIS	M	T	3	0-10	NL
SGW35	RC	Int	WWTP	NT	2	3-7	L
SGW36	NRC	Int	NAT	NT	3	7-11	NL
SGW37	RC	Int	WWTP	NT	3	10-15	L
SGW38	NRC	Int	NAT	NT	3	20-30	L
SGW40	RC	SS	GC	NT	3	5-15	L
SGW41	RC	Int	H	NT	1	2	L
SGW42	NRC	Int	L	NT	1	3-5	L
SGW43	NRC	Int	NAT	NT	3	23	NL
SGW45	NRC	Int	NAT	NT	3	10	NL
SGW46	NRC	Int	NAT	NT	1	3-5	NL
SGW48	NRC	SS	NAT	NT	1	1-6	L
SGW49	NRC	GM	M	T	0	0	NL
SGW52	NRC	SS	L	Nt	1	1-3	L

Table 7. Results of statistical analyses performed in Minitab 13 using the general linear model ANOVA. Statistically significant results are shown **in bold**.

Inorganic Nitrogen Factor (Mean1/Mean2)	F	p	IN Mean 1 (mg/l)	IN Mean 2 (mg/l)	n 1	n 2	Conclude
Season (Dry/Wet)	3.7	0.060	2.9	1.5	52	63	Not able to detect difference in means
RainEvent >0.5 inches (NoRain/Rain)	0.47	0.640	0.75	0.73	50	38	Not able to detect difference in means
Land Class Type	**7.5**	**<0.001**	**7.9**	**0.9**	**22**	**33**	**Greater IN golf course sites**
Fertilizer Season (Yes/No)	1.12	0.290	0.761	0.691	71	17	Not able to detect difference in means
Reclaimed Water (Irrigation/None)	**9.2**	**0.002**	**4.17**	**0.75**	**46**	**67**	**Greater IN at sites near reclaimed water use**
Nearby Lake (Lake/NoLake)	**4.2**	**0.040**	**1**	**0.66**	**23**	**65**	**Greater IN at sites with lake nearby**
Tidal Influence (Tide/NoTide)	**16.5**	**>0.001**	**0.42**	**1**	**41**	**47**	**Lower IN at sites with tidal influence**
Evapotranspiration Rate	**11**	**< 0.001**	**0.33**	**0.88**	**31**	**25**	**Greater IN at sites with greater evapo.**

Total Nitrogen Factor (Mean1/Mean2)	F	p	TN Mean 1 (mg/l)	TN Mean 2 (mg/l)	n 1	n 2	Conclude
Season (Dry/Wet)	0.47	0.490	5.1	3.9	52	63	Not able to detect difference in means
RainEvent >0.5 inches (NoRain/Rain)	0.01	0.990	2.46	2.49	50	38	Not able to detect difference in means
Land Class Type	**8.9**	**<0.001**	**12.9**	**2.7**	**22**	**33**	**Greater TN at golf course sites**
Fertilizer Season (Yes/No)	0.06	0.800	2.45	2.59	71	17	Not able to detect difference in means
Reclaimed Water (Irrigation/None)	**11.5**	**0.001**	**7.1**	**2.6**	**46**	**67**	**Greater TN at sites near reclaimed water use**
Nearby Lake (Lake/NoLake)	**8.1**	**0.005**	**3.1**	**2.2**	**23**	**65**	**Greater TN at sites with lake nearby**
Tidal Influence (Tide/NoTide)	**23.4**	**<0.001**	**1.65**	**3.2**	**41**	**47**	**Lower TN at sites with tidal influence**
Evapotranspiration Rate	**13.1**	**< 0.001**	**1.4**	**3.1**	**31**	**25**	**Greater TN at sites with greater evapo.**

Factor (Mean1/Mean2)	F	p	NH3 Mean 1 (mg/l)	NH3 Mean 2 (mg/l)	n 1	n 2	Conclude
Season (Dry/Wet)	**4.6**	**0.030**	**2.7**	**1.3**	**52**	**63**	**Greater ammonia during dry season**
RainEvent >0.5 inches (NoRain/Rain)	0.51	0.610	0.59	0.53	50	38	Not able to detect difference in means
Land Class Type	**7.5**	**<0.001**	**7.6**	**0.8**	**21**	**33**	**Greater ammonia at golf course sites**
Fertilizer Season (Yes/No)	0.57	0.454	0.55	0.61	71	17	Not able to detect difference in means
Reclaimed Water (Irrigation/None)	14.5	<0.001	3.3	6.8	46	67	Not able to detect difference in means
Nearby Lake (Lake/NoLake)	**4.1**	**0.050**	**0.72**	**0.51**	**23**	**65**	**Greater ammonia at sites near lake**
Tidal Influence (Tide/NoTide)	**4.1**	**0.020**	**2.8**	**1.2**	**53**	**61**	**Greater ammonia at sites with tidal influence**
Evapotranspiration Rate	**11**	**< 0.001**	**0.13**	**0.78**	**31**	**25**	**Greater ammonia at sites with greater evapo.**

Orhophosphate Factor (Mean1/Mean2)	F	p	OP Mean 1 (mg/l)	OP Mean 2 (mg/l)	n 1	n 2	Conclude
Season (Dry/Wet)	1.6	0.210	0.36	0.26	52	63	Not able to detect difference in means
RainEvent >0.5 inches (NoRain/Rain)	0.69	0.490	0.18	0.28	50	38	Not able to detect difference in means
Land Class Type	**10.7**	**<0.001**	**0.48**	**0.23**	**21**	**33**	**Greater OP at golf course sites**
Fertilizer Season (Yes/No)	0.01	0.930	0.21	0.28	71	17	Not able to detect difference in means
Reclaimed Water (Irrigation/None)	**16.6**	**< 0.001**	**0.41**	**0.24**	**46**	**67**	**Greater OP at sites near reclaimed water use**
Nearby Lake (Lake/NoLake)	1.4	0.250	0.18	0.25	23	65	Not able to detect difference in means
Tidal Influence (Tide/NoTide)	2.1	0.140	0.14	0.31	41	47	Not able to detect difference in means
Evapotranspiration Rate	**4.71**	**0.004**	**0.12**	**0.47**	**31**	**25**	**Greater OP at sites with greater evapo.**

Total Phosphate Factor (Mean1/Mean2)	F	p	TP Mean 1 (mg/l)	TP Mean 2 (mg/l)	n 1	n 2	Conclude
Season (Dry/Wet)	3.9	0.055	0.52	0.38	52	63	Not able to detect difference in means
RainEvent >0.5 inches (NoRain/Rain)	0.17	0.870	0.36	0.37	50	38	Not able to detect difference in means
Land Class Type	**12.2**	**<0.001**	**0.61**	**0.32**	**22**	**33**	**Greater TP at golf course sites**
Fertilizer Season (Yes/No)	0.07	0.791	0.36	0.36	71	17	Not able to detect difference in means
Reclaimed Water (Irrigation/None)	**11.5**	**0.001**	**0.51**	**0.4**	**46**	**67**	**Greater TP at sites near reclaimed water use**
Nearby Lake (Lake/NoLake)	0.51	0.480	0.26	0.4	23	65	Not able to detect difference in means
Tidal Influence (Tide/NoTide)	**10.6**	**0.002**	**0.16**	**0.54**	**41**	**47**	**Lower TP at sites with tidal influence**
Evapotranspiration Rate	**11**	**< 0.001**	**0.14**	**0.85**	**31**	**25**	**Greater TP at sites with greater evapo.**

Salinity Factor (Mean1/Mean2)	F	p	Sal Mean 1 PSU	Sal Mean 2 PSU	n 1	n 2	Conclude
Season (Dry/Wet)	**6.3**	**0.020**	**8.3**	**3.3**	**52**	**63**	**Lower salinity during wet season**
RainEvent >0.5 inches (NoRain/Rain)	3.6	0.060	2.3	3.1	50	38	Not able to detect difference in means
Land Class Type	1.9	0.090	3.9	9.5	33	22	Not able to detect difference in means
Fertilizer Season (Yes/No)	1.15	0.290	5.8	9.6	71	17	Not able to detect difference in means
Reclaimed Water (Irrigation/None)	1.53	0.220	3.3	6.8	46	67	Not able to detect difference in means
Nearby Lake (Lake/NoLake)	**4.66**	**0.030**	**1.9**	**7.45**	**67**	**68**	**Lower salinity at sites near lakes**
Tidal Influence (Tide/NoTide)	0.58	0.450	7.4	4.8	33	36	Not able to detect difference in means
Evapotranspiration Rate	11	< 0.001	2.1	7.1	15	19	**Higher salinity at sites with greater evapo.**

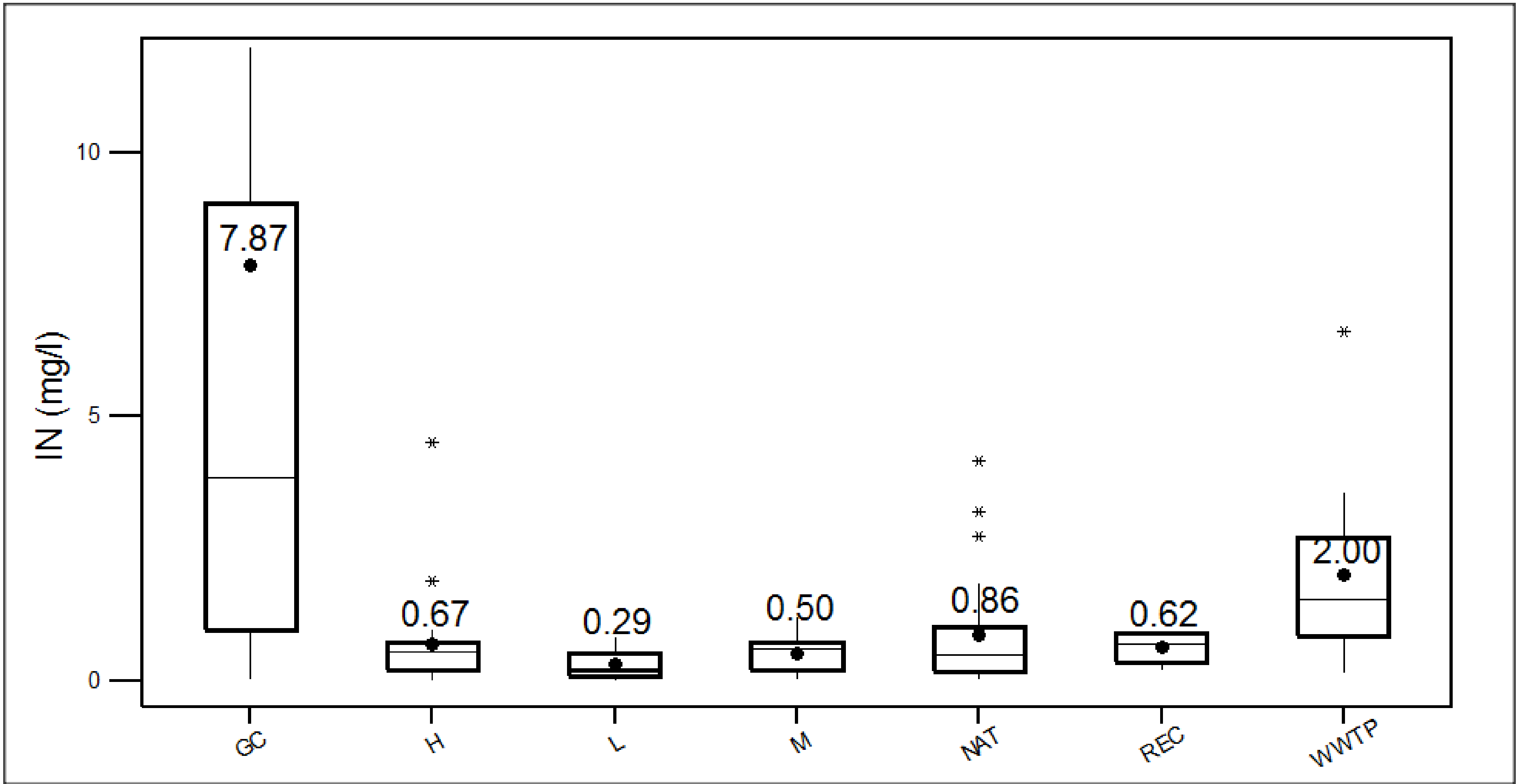

Figure 27. Inorganic nitrogen (IN) by land use class. Mean represented by dot, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line. Golf course (GC), High density residential (H), Medium density (M), Low density (L), Natural (Nat), Recreation (Rec), and wastewater treatment (WWTP).

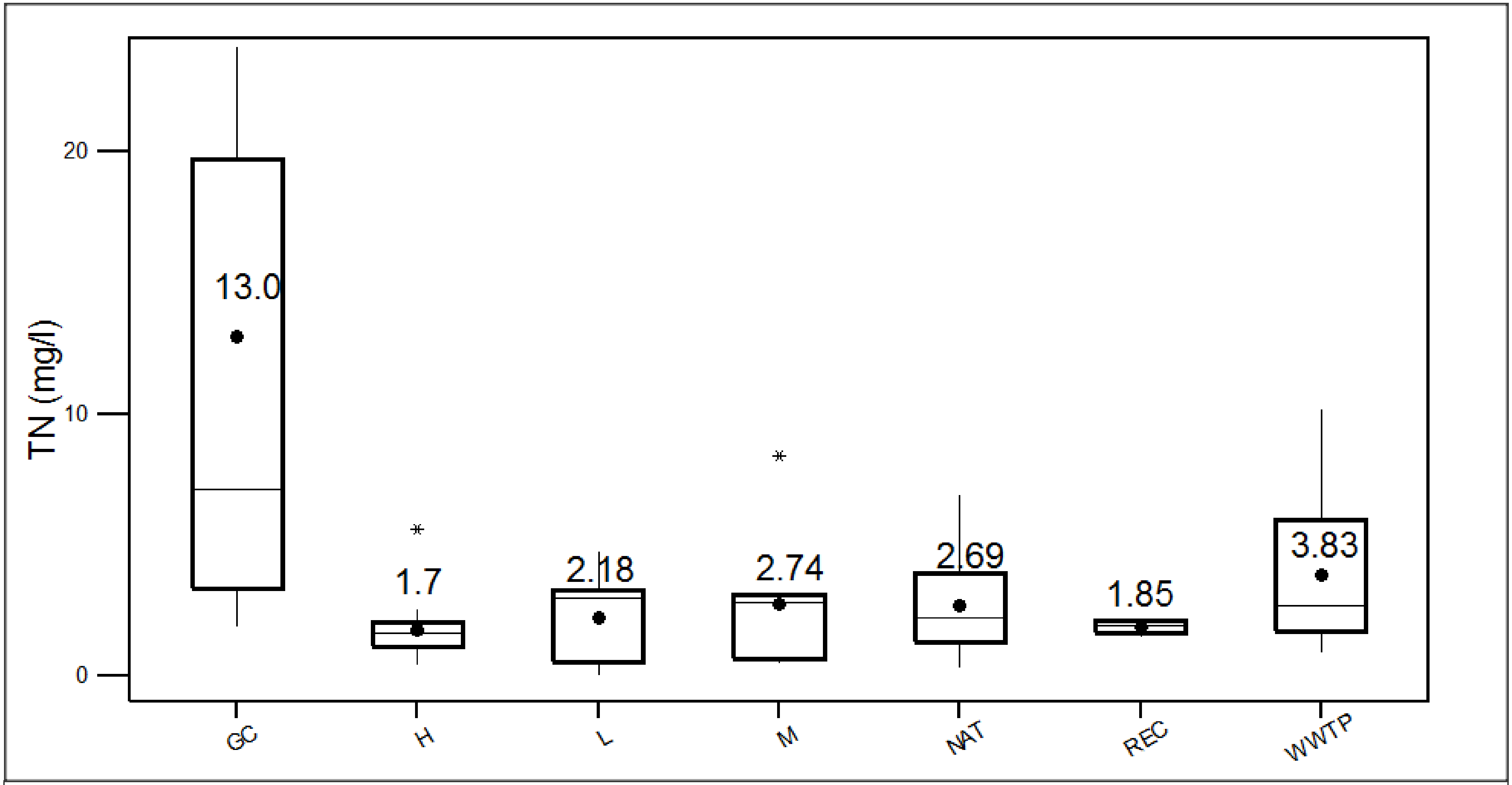

Figure 28. Total nitrogen (TN) by land use class. Mean represented by dot, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line. Golf course (GC), High density residential (H), Medium density (M), Low density (L), Natural (Nat), Recreation (Rec), and wastewater treatment (WWTP).

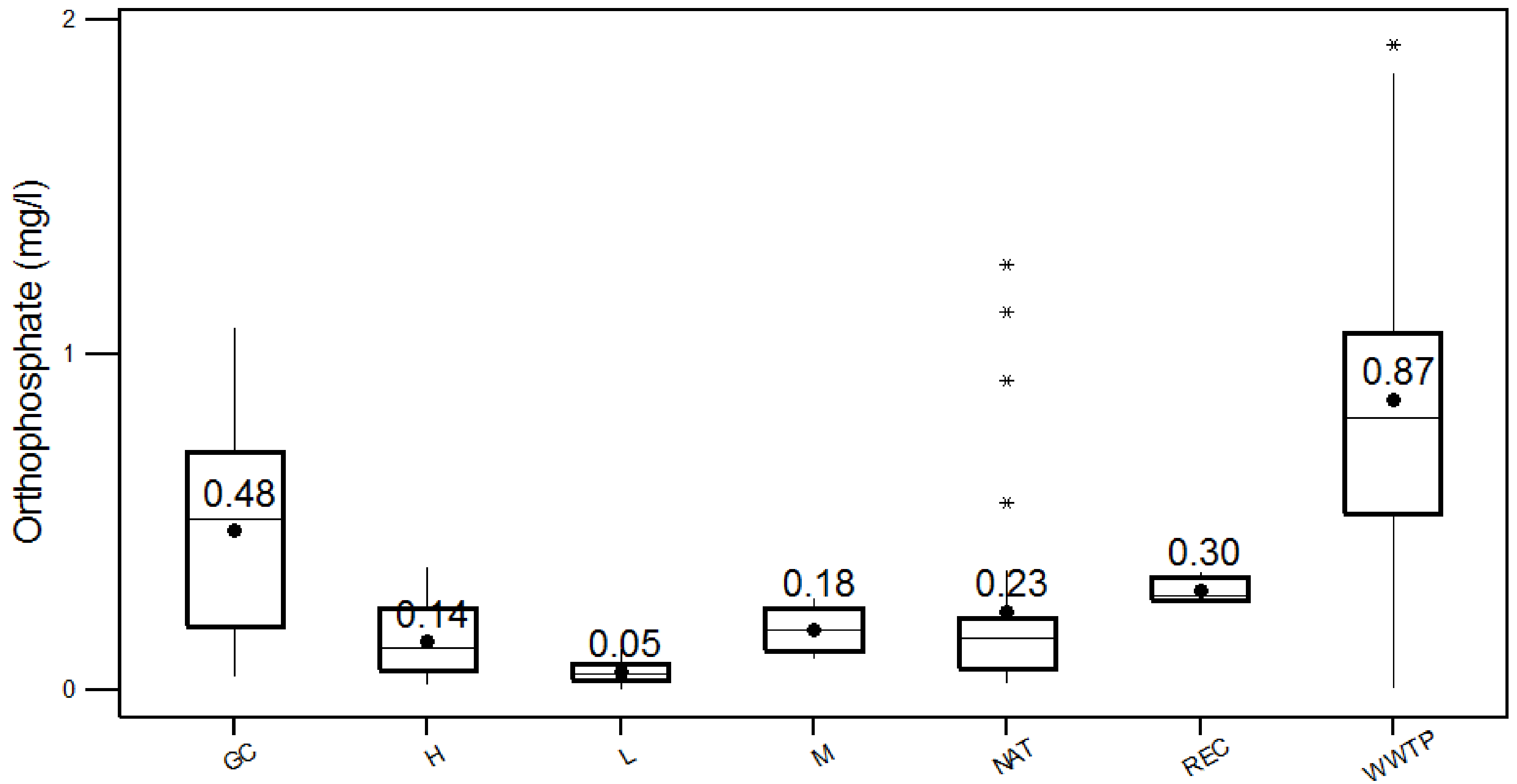

Figure 29. Orthophosphate (OP) by land use class. Mean represented by dot, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line. Golf course (GC), High density residential (H), Medium density (M), Low density (L), Natural (Nat), Recreation (Rec), and wastewater treatment (WWTP).

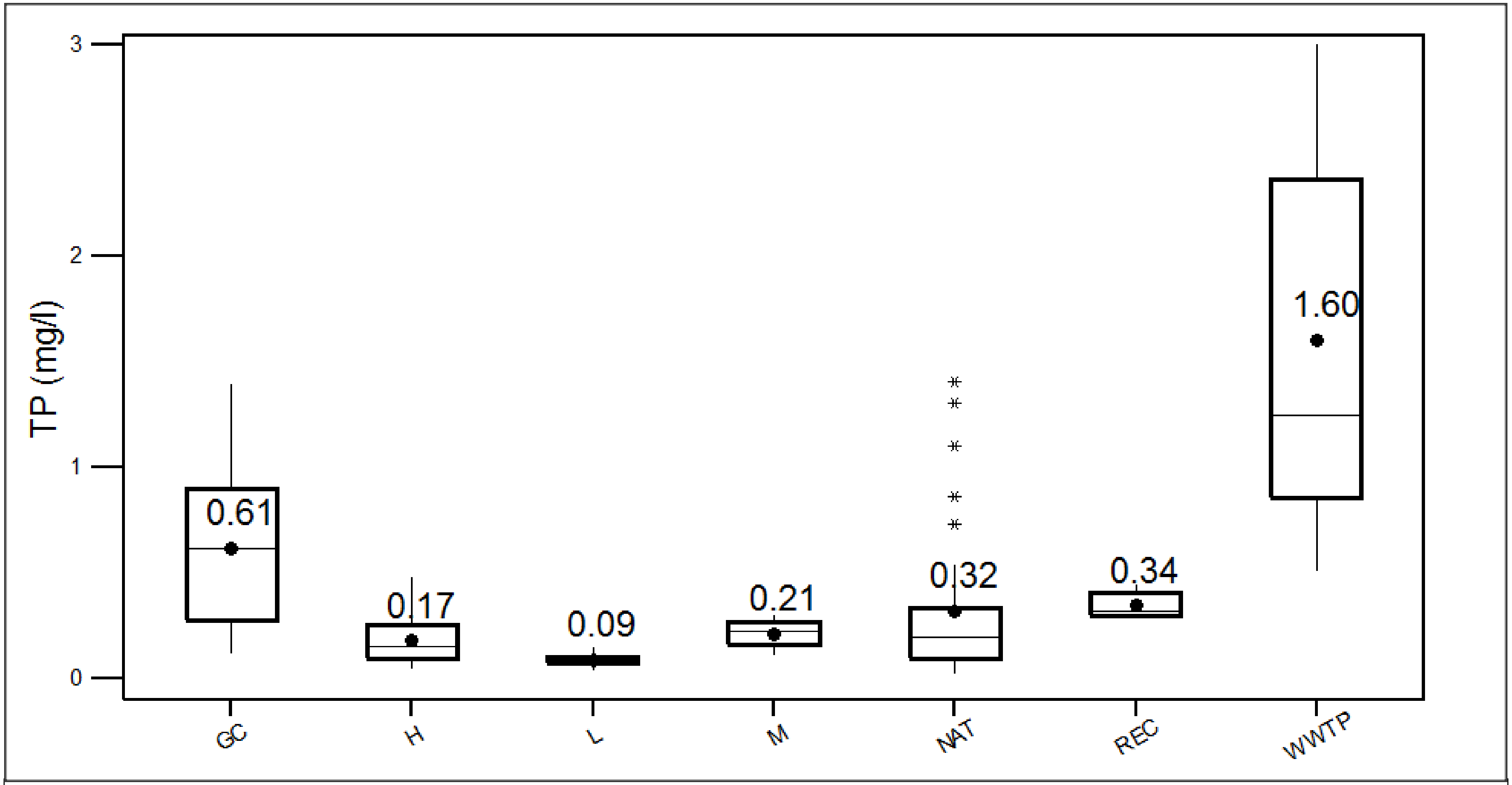

Figure 30. Total phosphorus (TP) by land use class. Mean represented by dot, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line. Golf course (GC), High density residential (H), Medium density (M), Low density (L), Natural (Nat), Recreation (Rec), and wastewater treatment (WWTP).

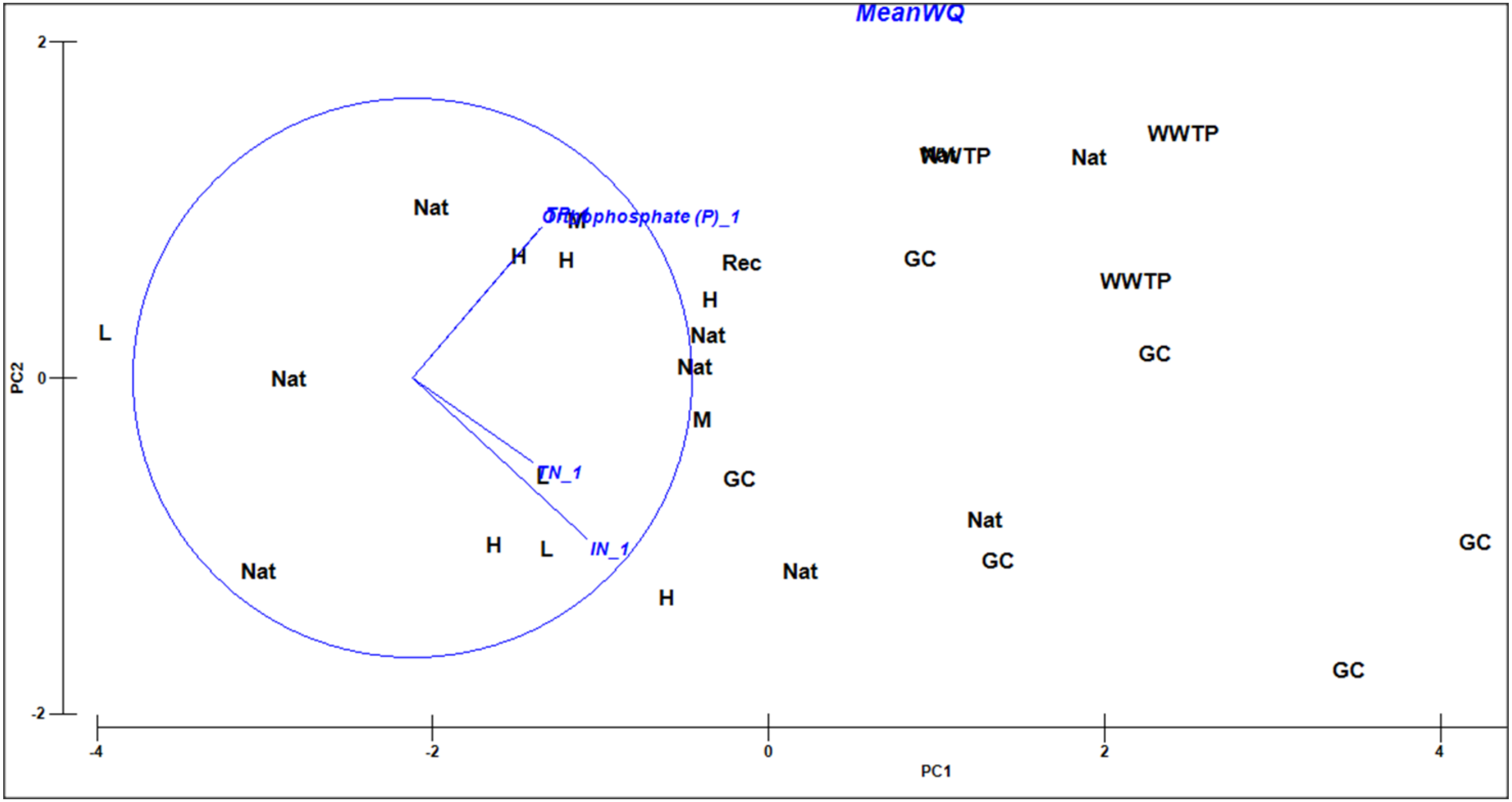

Figure 31. PCA using nutrient concentration data only. Sites are identified by land use type. Sites with higher nutrient concentrations are plotted to the right side of graph.

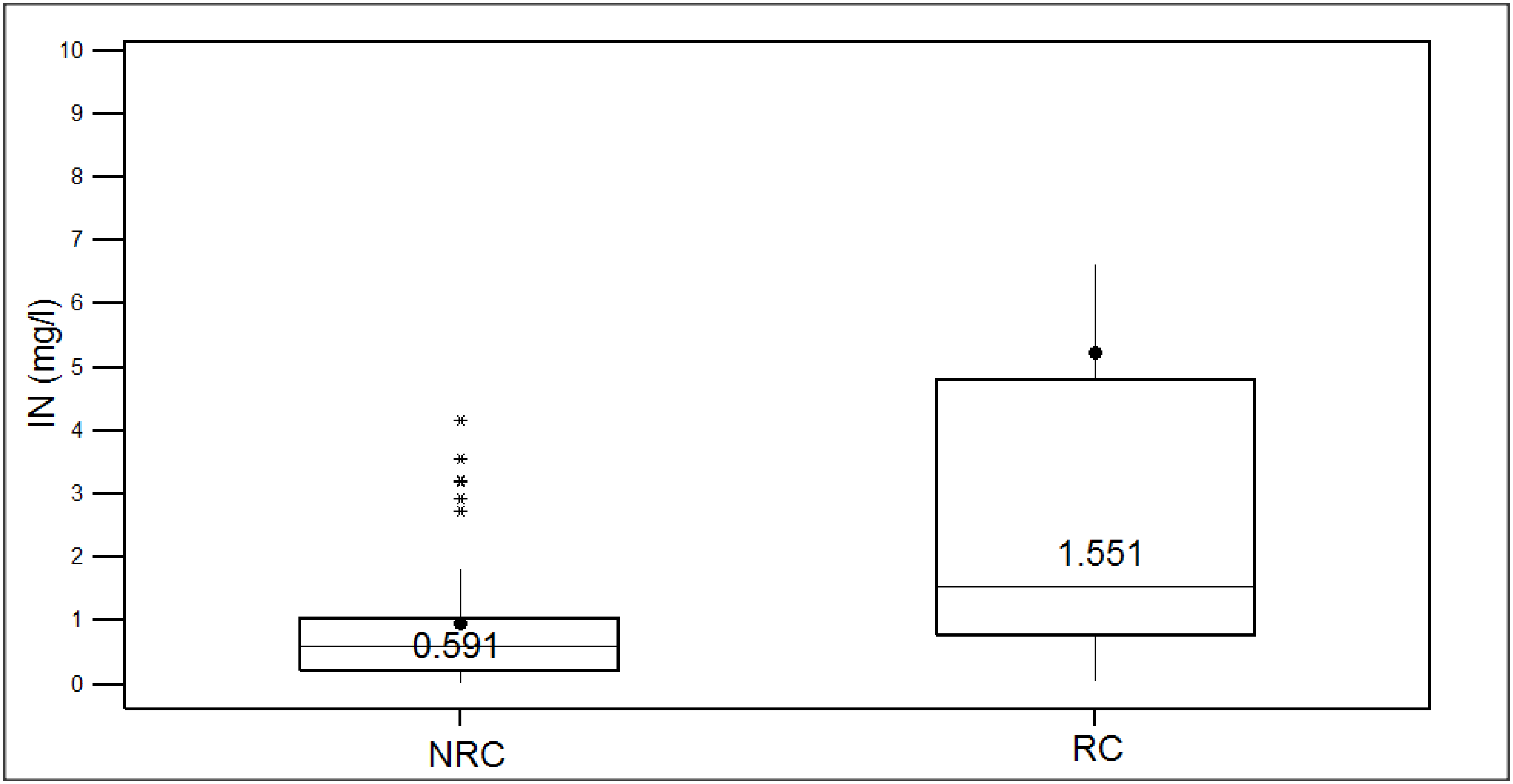

Figure 32. Inorganic nitrogen (IN) at sites near reclaim water (RC) irrigation and those without irrigation nearby (NRC). Mean represented by dot, median by horizontal line within box and labeled, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line. Stars are outliers.

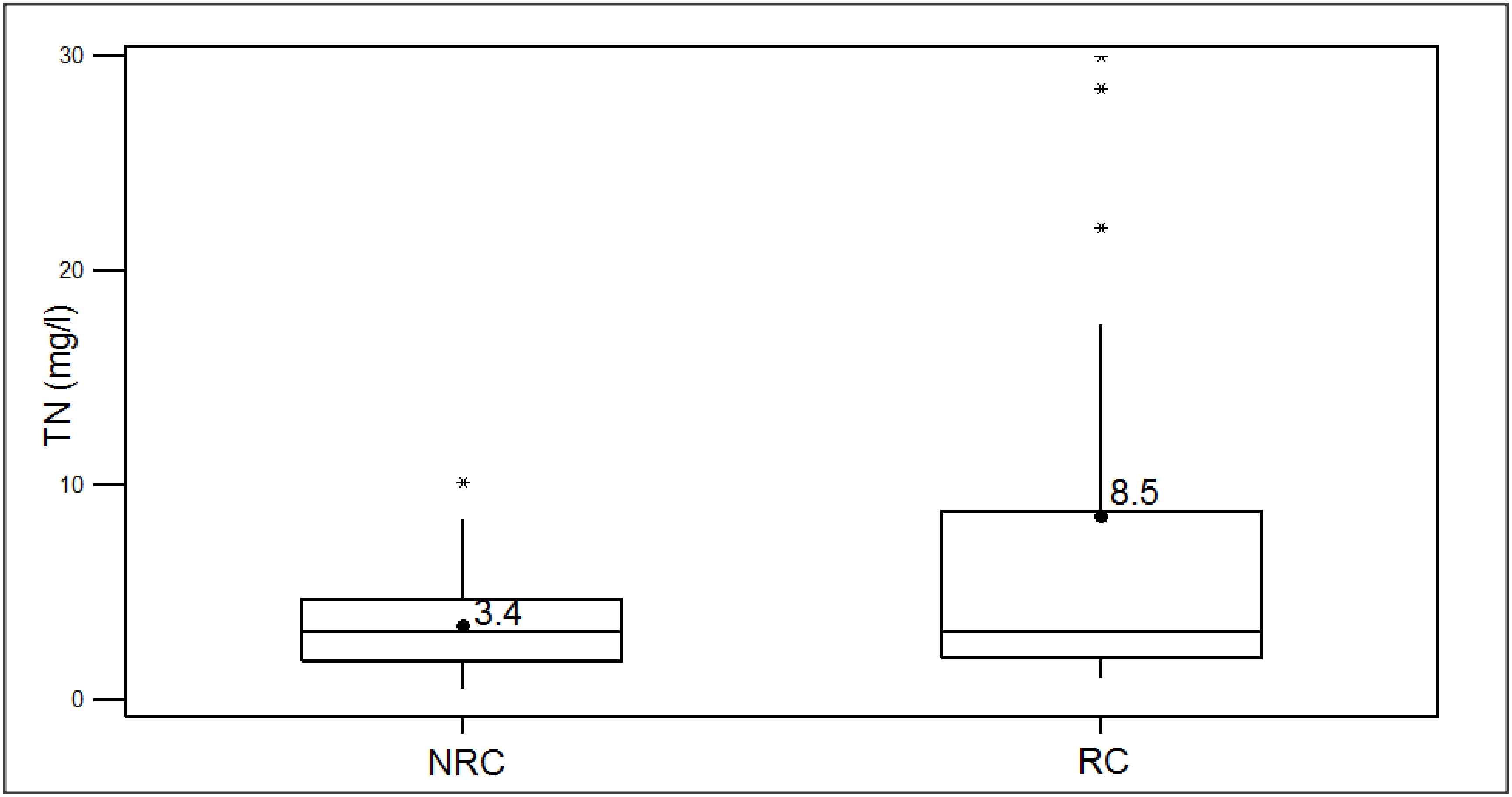

Figure 33. Total nitrogen (TN) at sites near reclaim water (RC) irrigation and those without irrigation nearby (NRC). Mean represented by dot and labeled, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line.

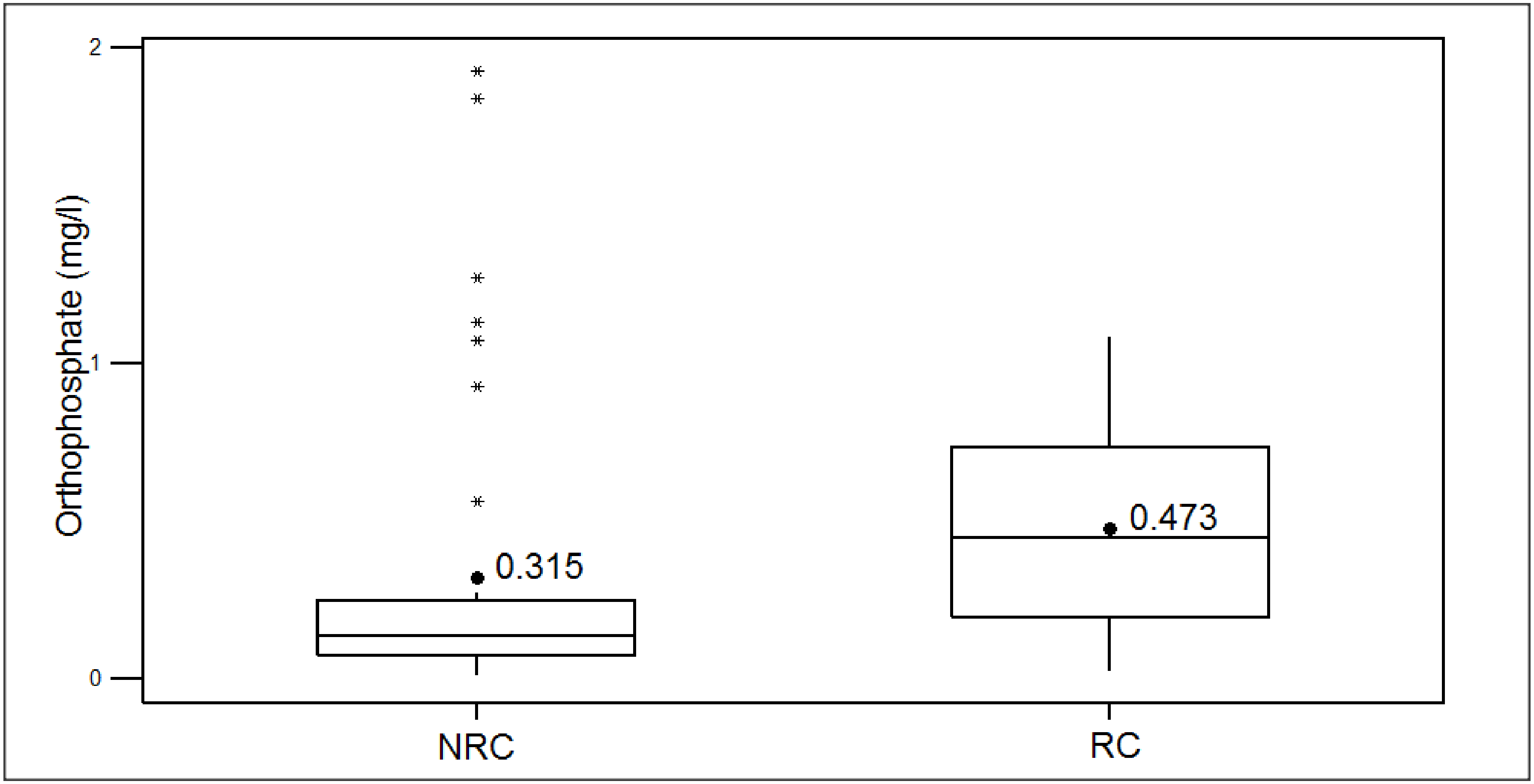

Figure 34. Orthophosphate (OP) at sites near reclaim water (RC) irrigation and those without irrigation nearby (NRC). Mean represented by dot and labeled, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line. Stars are outliers.

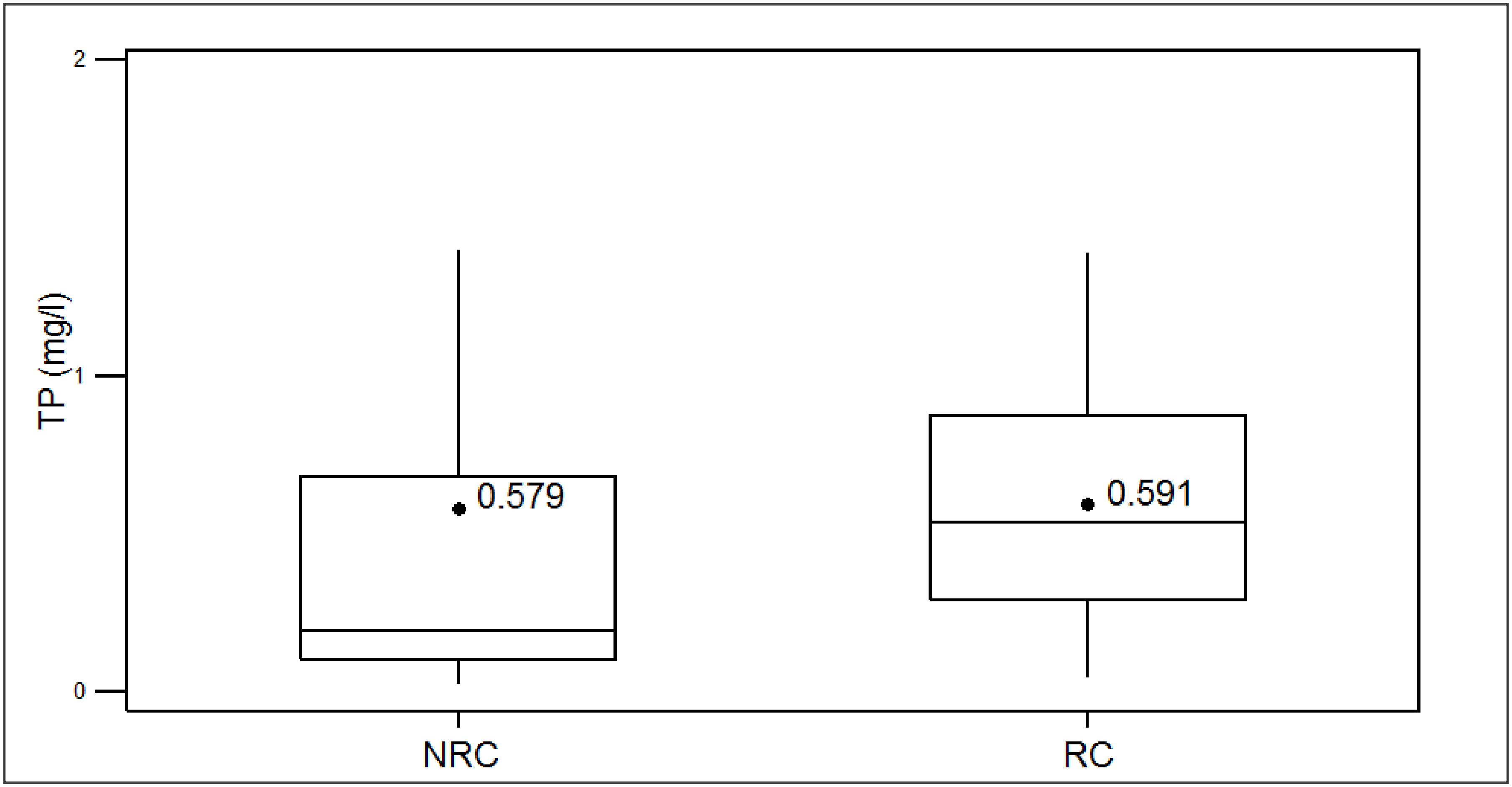

Figure 35. Total phosphorus (TP) at sites near reclaim water (RC) irrigation and those without irrigation nearby (NRC). Mean represented by dot and labeled, median by horizontal line within box, 25th and 75th quartiles by upper and lower boundaries of box, and range by vertical line. Stars are outliers.

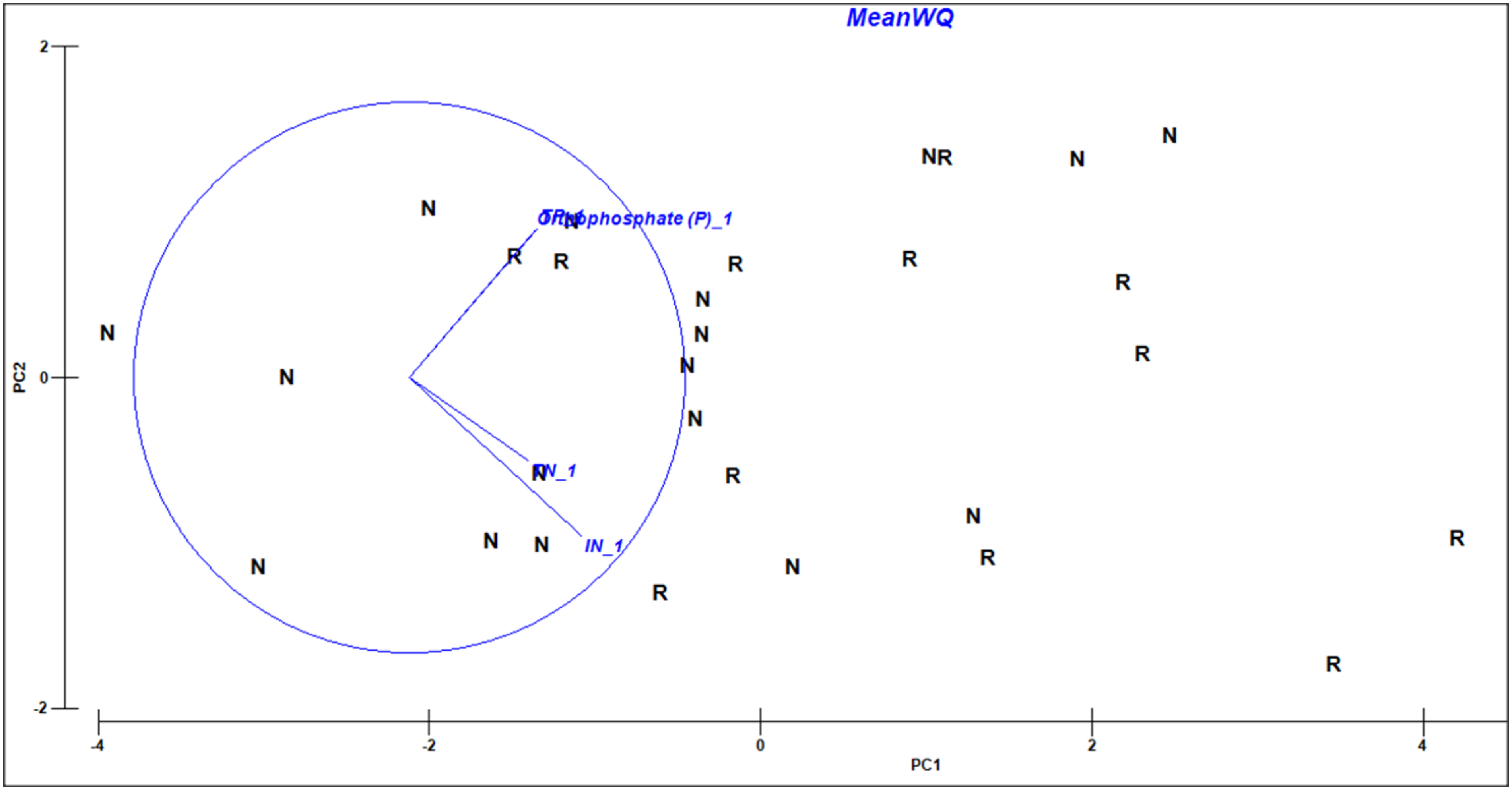

Figure 36. PCA on concentration data only showing sites with (R) and without (N) reclaim water irrigation in vicinity. Sites with higher nutrient concentrations are plotted to the right side of graph.

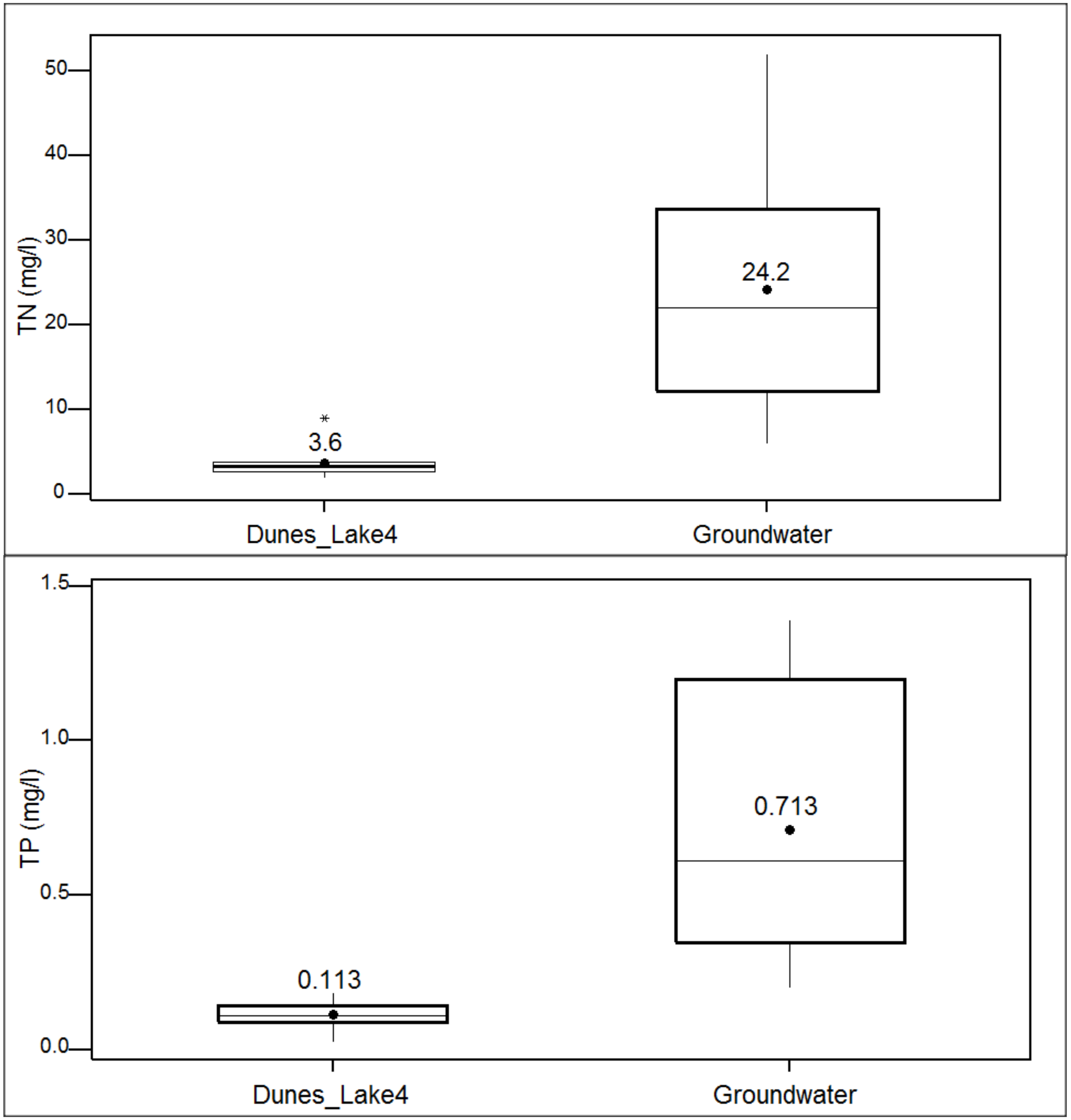

Figure 37. Groundwater near The Dunes stormwater ponds is significantly greater in TN and TP than the ponds.

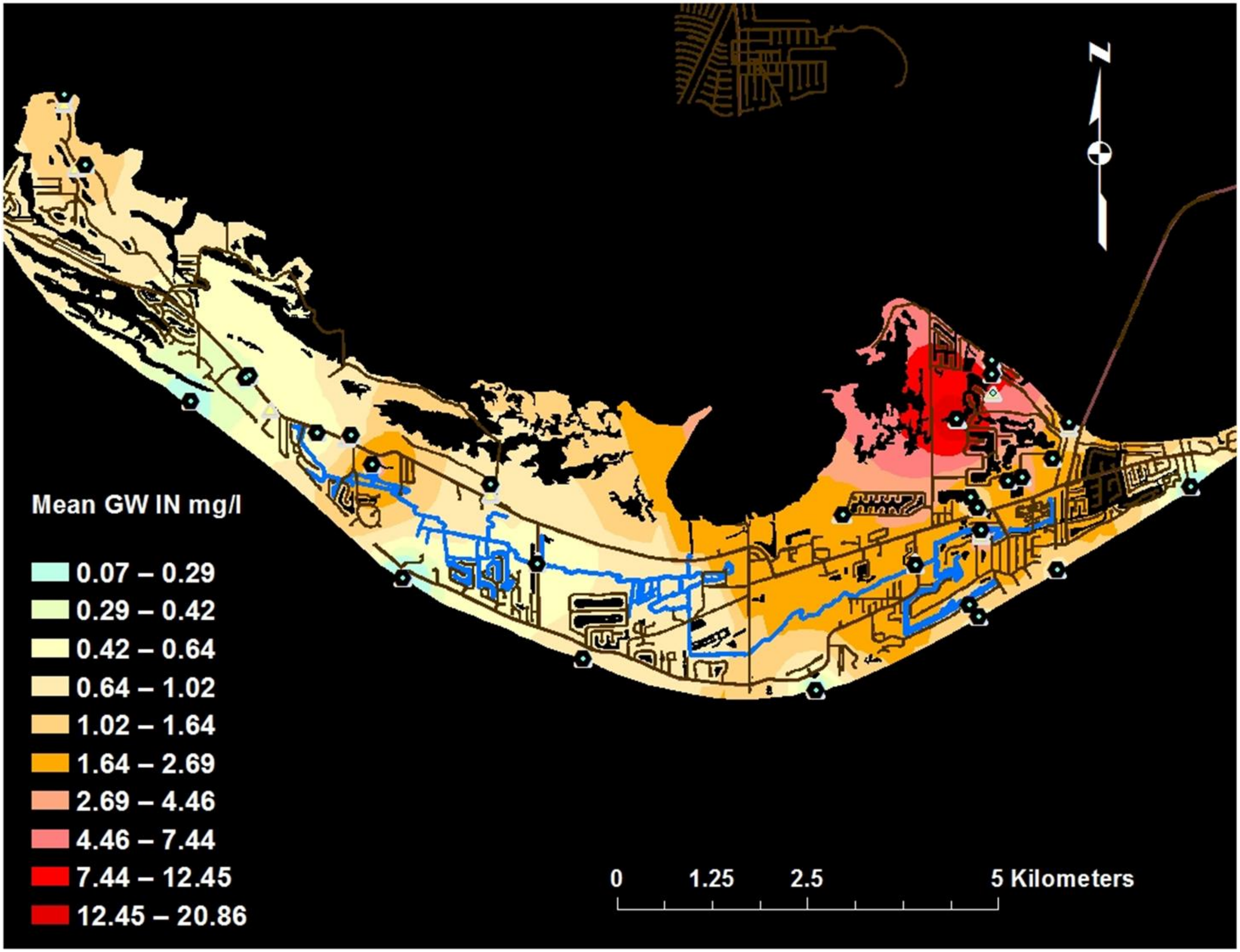

Figure 38. GIS-derived map of interpolated IN concentrations in Sanibel's surficial aquifer groundwater. Maps are intended to estimate very broad characteristics and not detailed local conditions due to limited number of data collection points within a large area of interpolation.

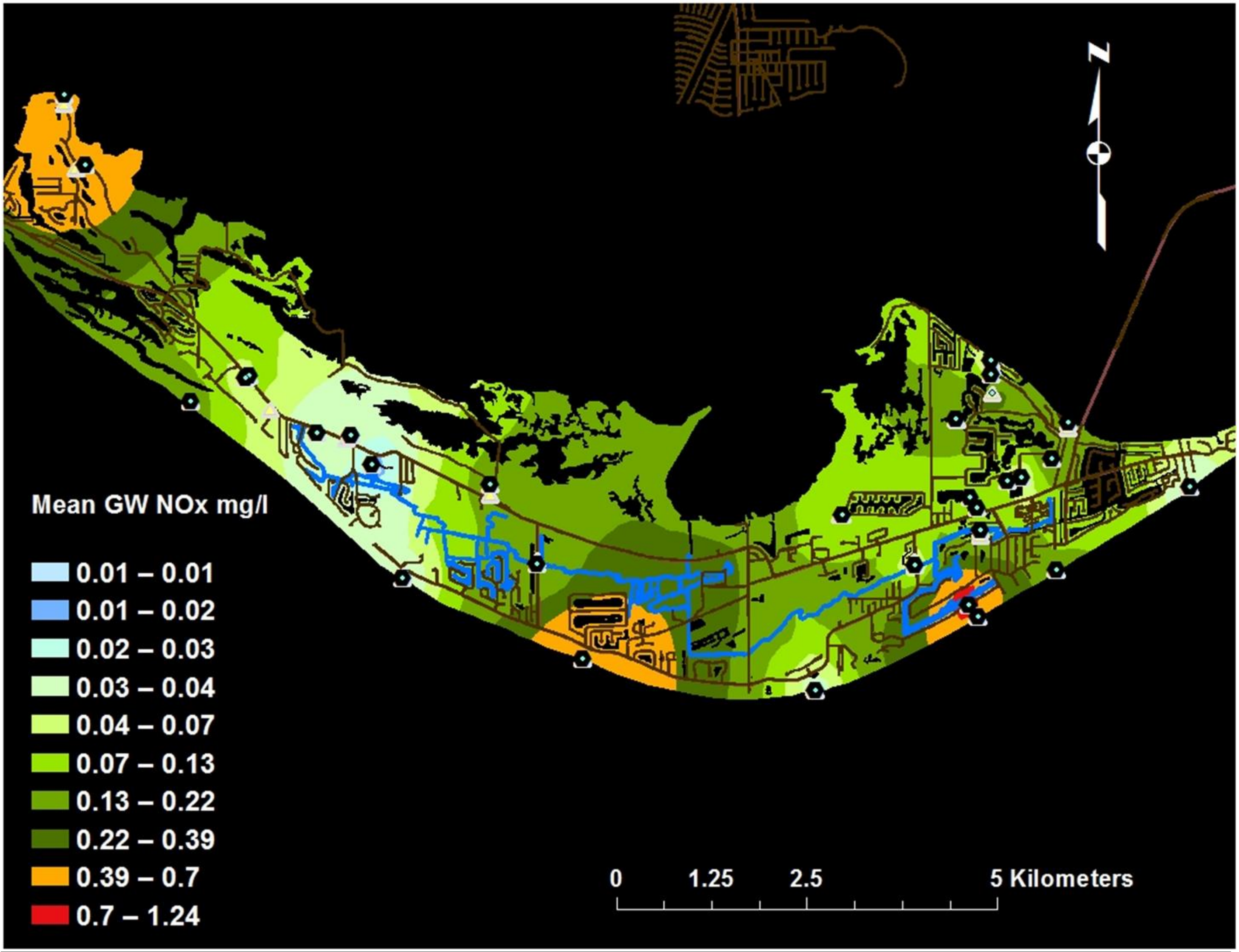

Figure 39. GIS-derived map of interpolated NOx concentrations in Sanibel's surficial aquifer groundwater. Maps are intended to estimate very broad characteristics and not detailed local conditions due to limited number of data collection points within a large area of interpolation.

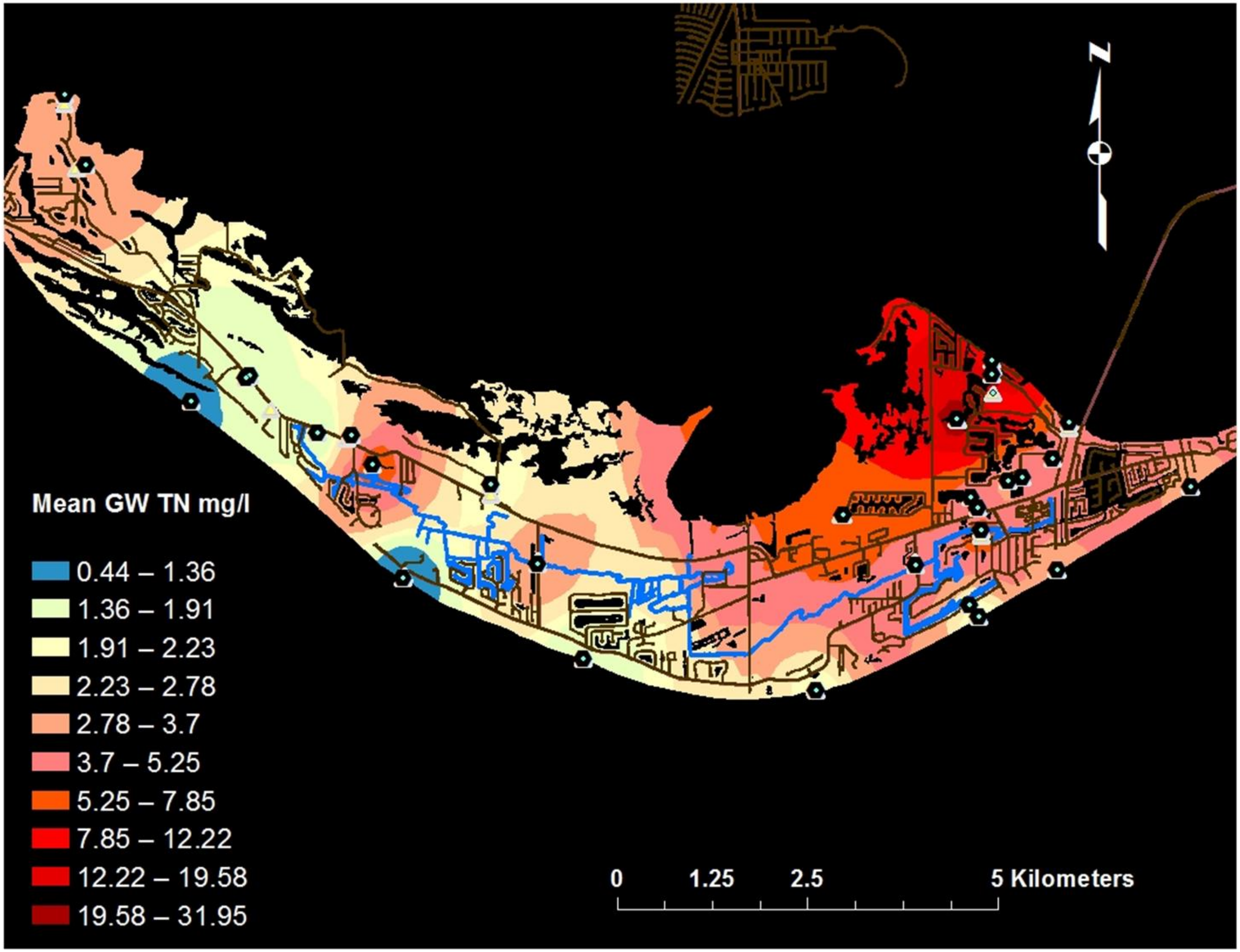

Figure 40. GIS-derived map of interpolated TN concentrations in Sanibel's surficial aquifer groundwater. Maps are intended to estimate very broad characteristics and not detailed local conditions due to limited number of data collection points within a large area of interpolation.

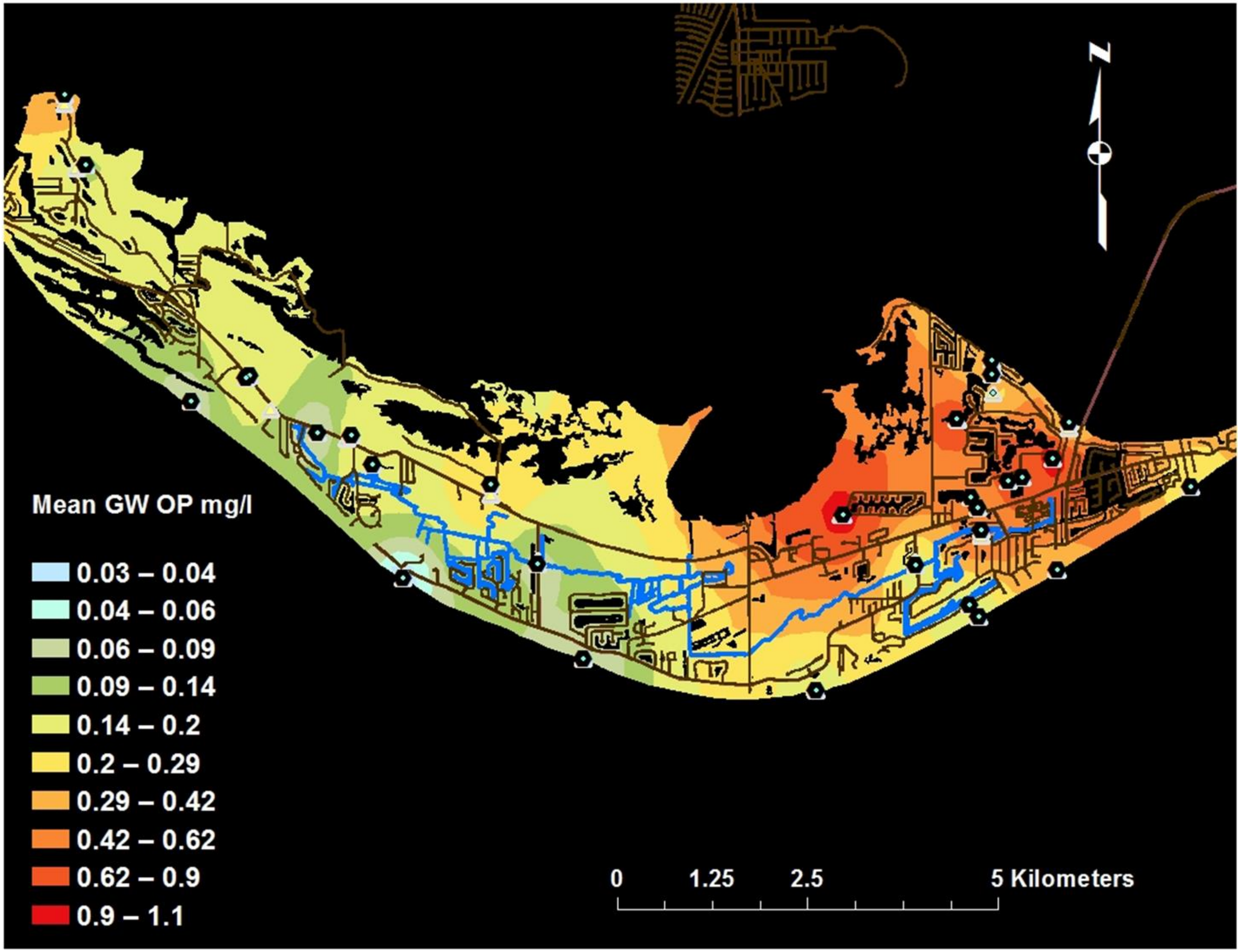

Figure 41. GIS-derived map of interpolated OP concentrations in Sanibel's surficial aquifer groundwater. Maps are intended to estimate very broad characteristics and not detailed local conditions due to limited number of data collection points within a large area of interpolation.

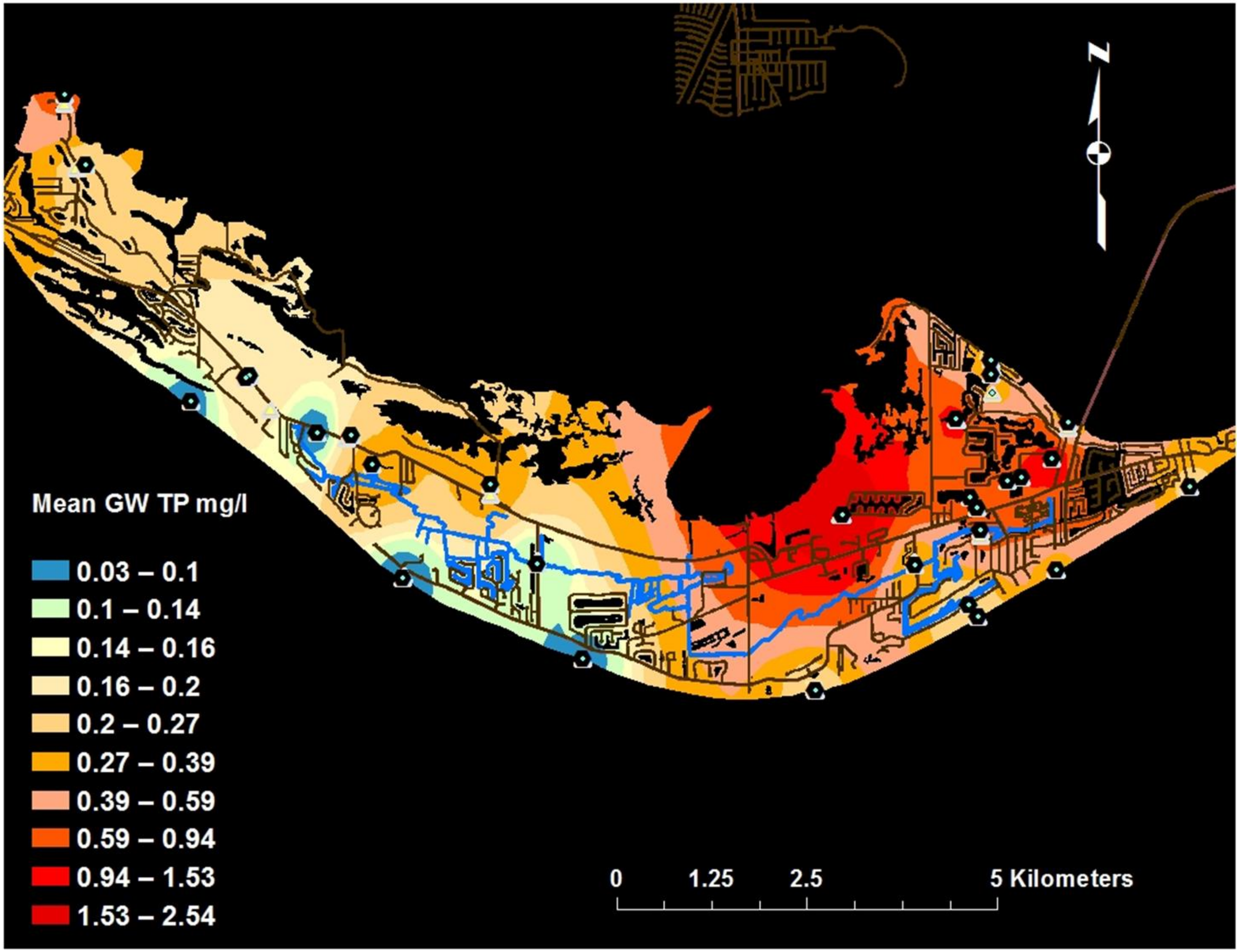

Figure 42. GIS-derived map of interpolated TP concentrations in Sanibel's surficial aquifer groundwater. Maps are intended to estimate very broad characteristics and not detailed local conditions due to limited number of data collection points within a large area of interpolation.

Site	Receiving Waterbody	DS Est NH3 Load (kg/yr)	DS Estimated Annual NOx Load (kg/yr)	DS Estimated Annual IN Load (kg/yr)	DS Estimated Annual TN Load (kg/yr)	DS Estimated Annual OP Load (kg/yr)	DS Estimated Annual TP Load (kg/yr)	WS Est Annual NH3 Load (kg/yr)	WS Estimated Annual NOx Load (kg/yr)	WS Estimated Annual IN Load (kg/yr)	WS Estimated Annual TN Load (kg/yr)	WS Estimated Annual OP Load (kg/yr)	WS Estimated Annual TP Load (kg/yr)
Gulf Shoreline Discharges													
GW49	Gulf	28.6	2.8	31.4	603.3	35.5	38.7	39.8	5.0	44.8	660.6	54.0	62.6
GW01	Gulf	201.5	3.6	205.1	641.5	97.4	122.8	171.3	141.9	313.2	1,149.1	105.9	120.9
GW03	Gulf	153.5	15.9	169.4	344.2	95.2	103.4	88.1	4.1	92.3	925.9	67.1	84.9
GW05	Gulf	17.4	0.6	18.0	148.3	18.3	22.6	62.1	24.1	86.1	1,014.5	64.0	73.5
GW07	Gulf	5.0	80.3	85.4	142.0	6.3	7.0	4.3	377.4	381.8	629.8	31.6	41.1
GW09	Gulf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GW11	Gulf	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total Gulf Discharge			**103**	**509**	**1,879**	**253**	**295**	**366**	**553**	**918**	**4,380**	**323**	**383**
Sound Discharges													
GW17	Sound	83.7	3.0	86.7	222.0	26.3	60.2	8.6	87.1	95.6	386.4	47.9	48.5
GW13	Sound	1.8	3.5	5.3	18.0	0.5	1.0	6.2	0.0	6.3	19.3	0.9	1.1
GW19	Sound	0.0	0.0	0.0	0.0	0.0	0.0	9.1	1.5	10.6	31.3	2.6	2.9
GW21	Sound	0.4	0.0	0.4	4.5	0.3	0.4	1.5	0.1	1.6	5.3	0.4	0.4
GW23	Sound	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.8	3.6	14.7	2.5	2.6
GW25	Sound	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GW27	Sound	0.0	0.0	0.0	0.0	0.0	0.0	819.5	27.5	846.9	1,555.8	79.9	104.6
GW29	Sound	9.6	0.0	9.7	18.5	0.3	0.3	6.3	0.6	6.9	16.2	0.4	0.5
GW33	Sound	164.2	3.5	167.7	711.5	49.1	57.0	276.9	144.2	421.1	1,479.7	68.7	74.2
Total Sound Discharge		**260**	**10**	**270**	**974**	**77**	**119**	**1,130**	**263**	**1,393**	**3,509**	**203**	**235**
Discharges to Sanibel Slough													
GW40	Slough	599.1	1.1	600.3	929.4	96.4	99.8	110.7	8.7	119.4	271.3	31.2	32.0
GW48	Slough	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GW52	Slough	7.4	5.4	12.9	80.2	1.9	2.3	12.1	5.7	17.8	164.7	3.9	4.5
Total Slough Discharge		**607**	**7**	**613**	**1,010**	**98**	**102**	**123**	**14**	**137**	**436**	**35**	**37**
Total Island Discharge		**866**	**120**	**1,392**	**3,864**	**428**	**516**	**1,618**	**830**	**2,448**	**8,325**	**561**	**654**

Table 8. Nutrient loading estimates for dry (DS) and wet seasons (WS) by site and receiving waterbody.

Site	Receiving Waterbody	Total Estimated Annual NOx Load (kg/yr)	Total Estimated Annual IN Load (kg/yr)	Total Estimated Annual TN Load (kg/yr)	Total Estimated Annual OP Load (kg/yr)	Total Estimated Annual TP Load (kg/yr)
Gulf Shoreline Discharges						
GW49	Gulf	7.8	76.2	1,264.0	89.5	101.2
GW01	Gulf	145.5	518.3	1,790.7	203.3	243.8
GW03	Gulf	20.0	261.7	1,270.1	162.4	188.4
GW05	Gulf	24.7	104.2	1,162.8	82.3	96.1
GW07	Gulf	457.8	467.1	771.8	37.9	48.1
GW09	Gulf	0.0	0.0	0.0	0.0	0.0
GW11	Gulf	0.0	0.0	0.0	0.0	0.0
Total Gulf Discharge		**656**	**1,427**	**6,259**	**575**	**678**
Sound Discharges						
GW17	Sound	90.0	182.4	608.4	74.2	108.7
GW13	Sound	3.5	11.6	37.3	1.4	2.1
GW19	Sound	1.5	10.6	31.3	2.6	2.9
GW21	Sound	0.1	2.0	9.8	0.6	0.8
GW23	Sound	1.8	3.6	14.7	2.5	2.6
GW25	Sound	0.0	0.0	0.0	0.0	0.0
GW27	Sound	27.5	846.9	1,555.8	79.9	104.6
GW29	Sound	0.6	16.6	34.7	0.7	0.8
GW33	Sound	147.7	588.8	2,191.1	117.9	131.2
Total Sound Discharge		**273**	**1,663**	**4,483**	**280**	**354**
Discharges to Sanibel Slough						
GW40	Slough	9.8	719.7	1,200.7	127.7	131.8
GW48	Slough	0.0	0.0	0.0	0.0	0.0
GW52	Slough	11.1	30.7	244.9	5.9	6.8
Total Slough Discharge		**21**	**750**	**1,446**	**134**	**139**
Total Island Discharge		**950**	**3,840**	**12,188**	**989**	**1,170**

Table 8 b. Total nutrient loading estimates from Sanibel's surficial aquifer by site and receiving waterbody.

Figure 43. GIS-derived map of mean surficial aquifer salinity from interpolation of sampling results. Red color indicates higher salinities and blue lower salinities.

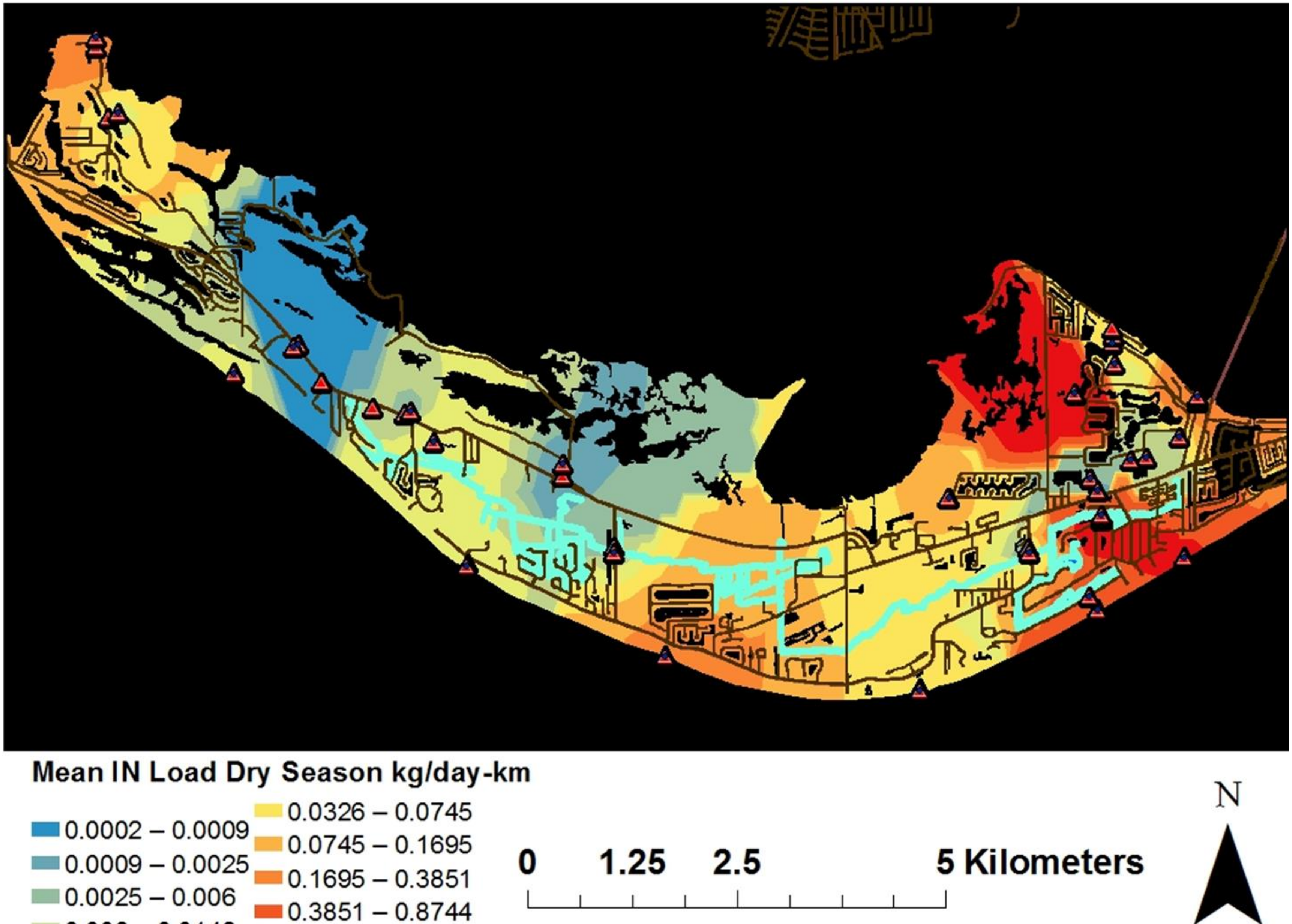

Figure 44. GIS-derived map of mean dry season IN loading produced from interpolation of surficial aquifer sampling results and flow estimates. Red color indicates higher loading rates to surface waters while blue color indicates low loading rate.

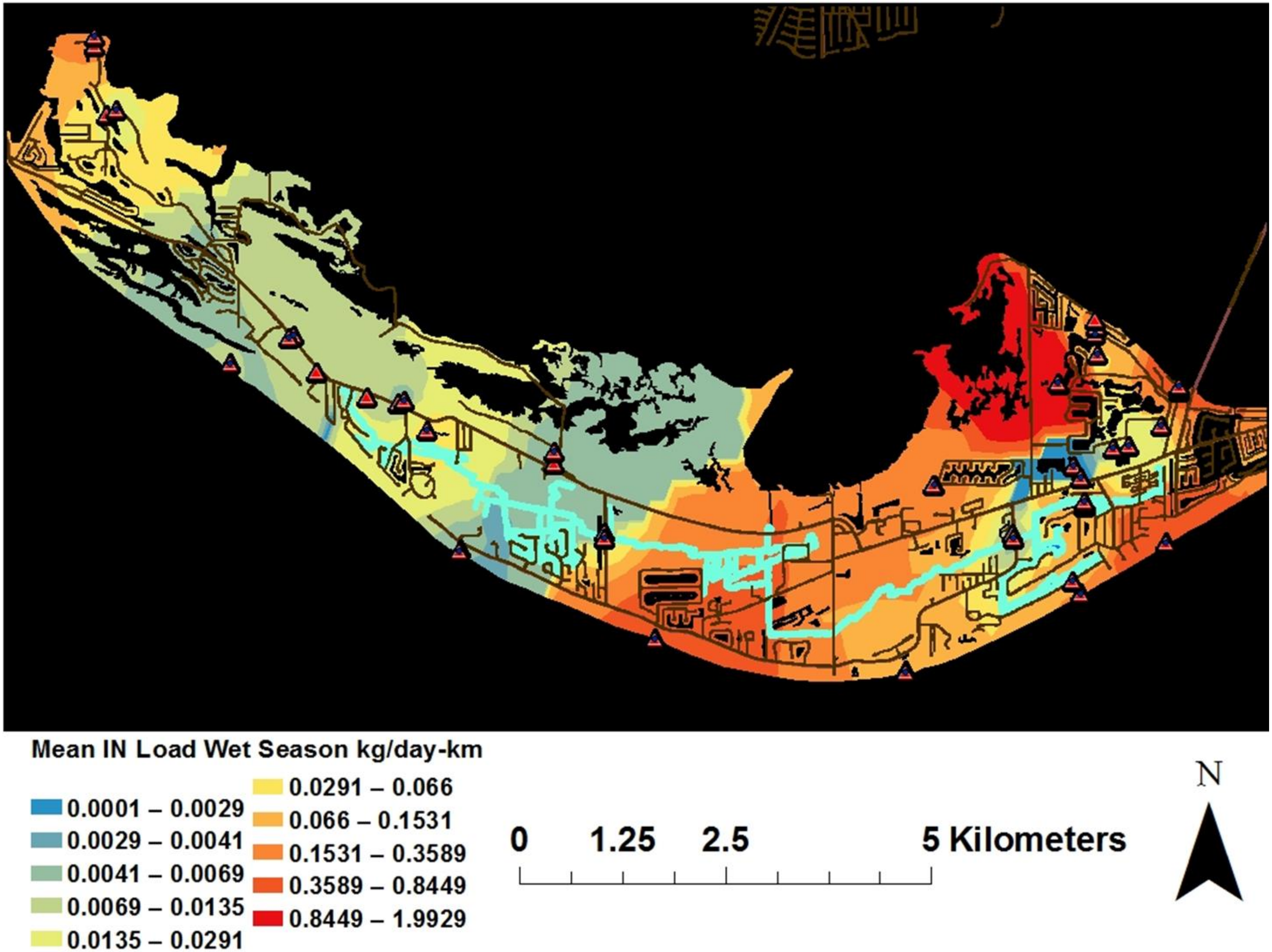

Figure 45. GIS-derived map of mean wet season IN loading produced from interpolation of surficial aquifer sampling results and flow estimates. Red color indicates higher loading rates to surface waters while blue color indicates low loading rate.

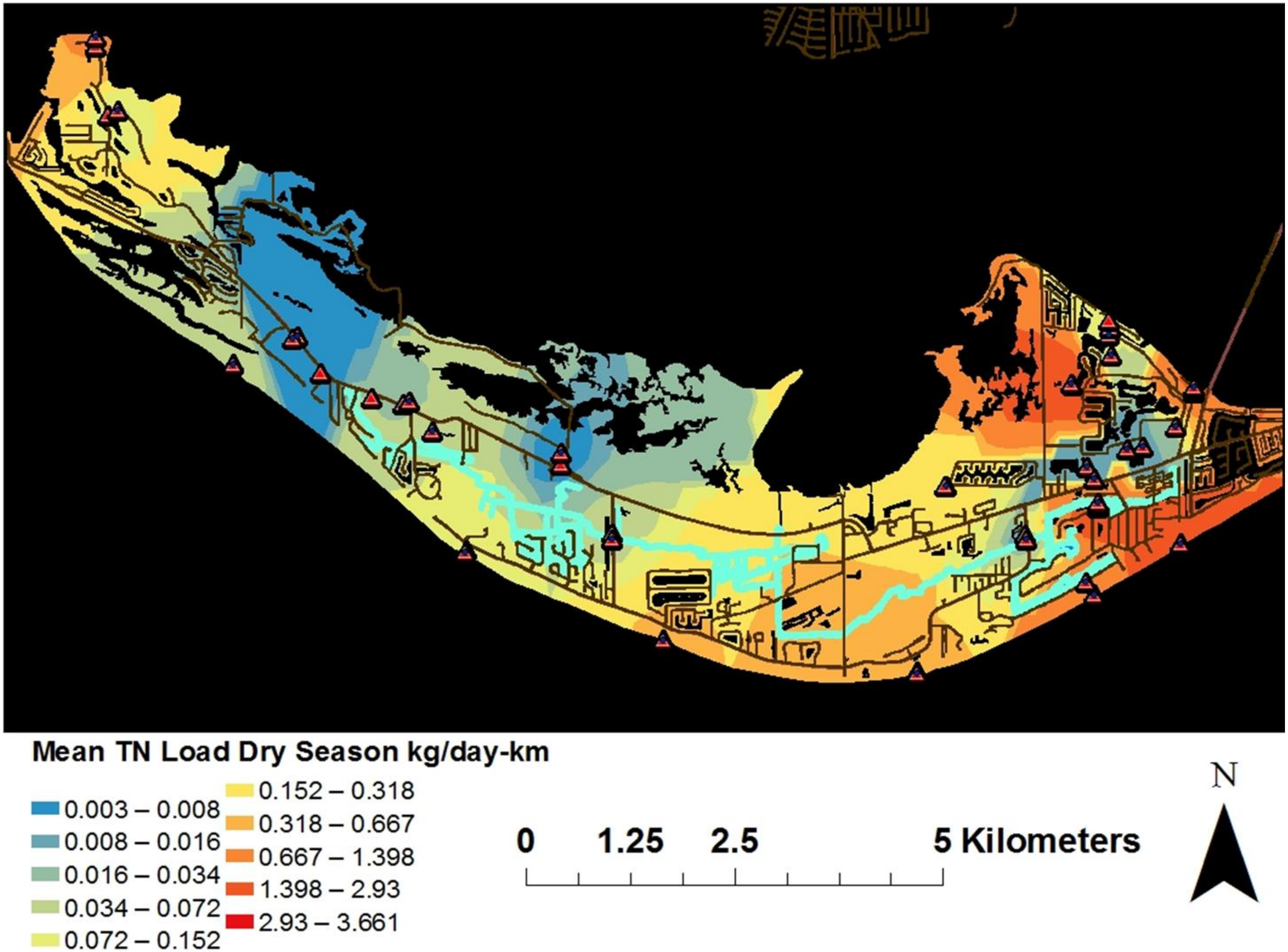

Figure 46. GIS-derived map of mean dry season TN loading produced from interpolation of surficial aquifer sampling results and flow estimates. Red color indicates higher loading rates to surface waters while blue color indicates low loading rate.

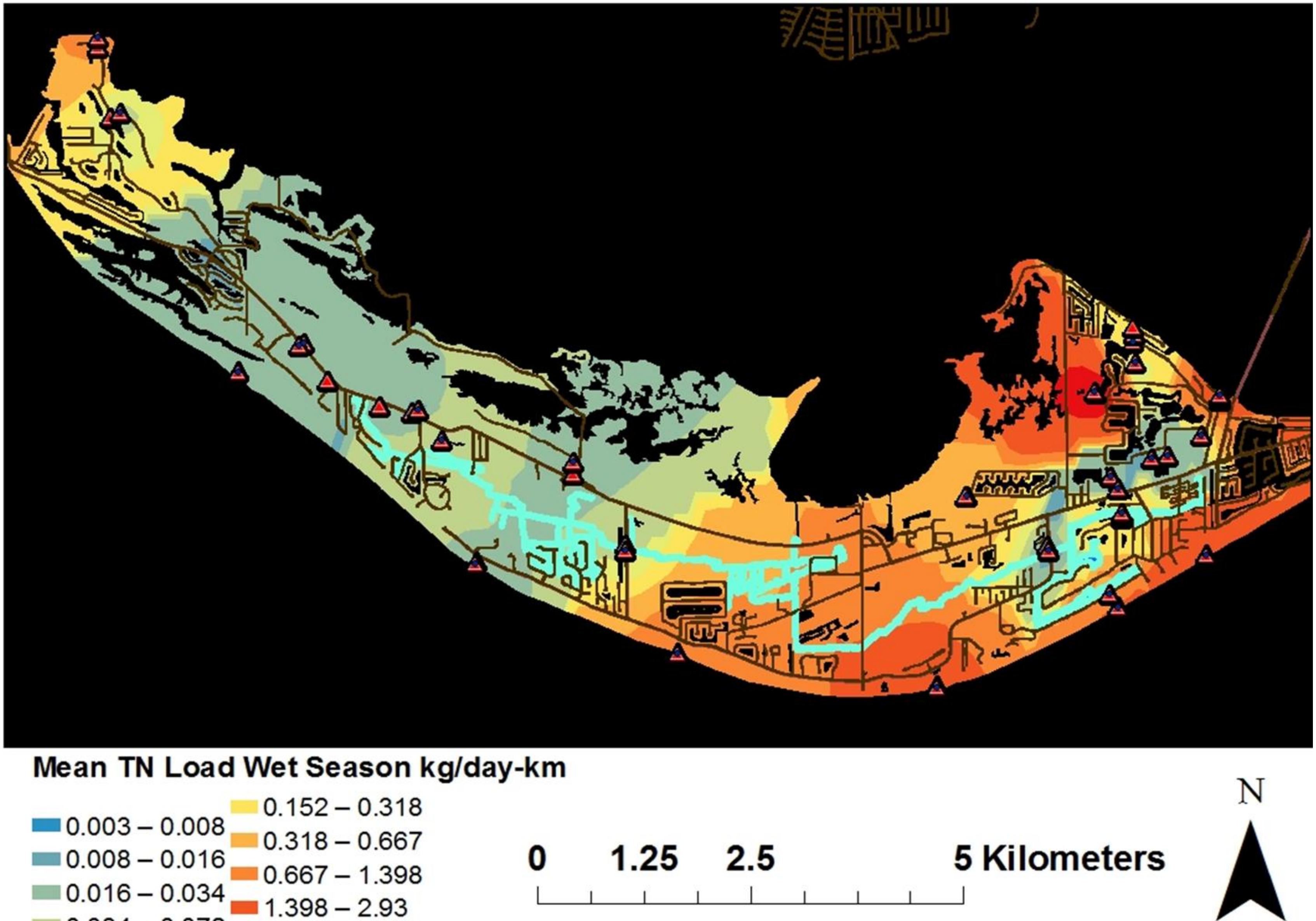

Figure 47. GIS-derived map of mean wet season TN loading produced from interpolation of surficial aquifer sampling results and flow estimates. Red color indicates higher loading rates to surface waters while blue color indicates low loading rate.

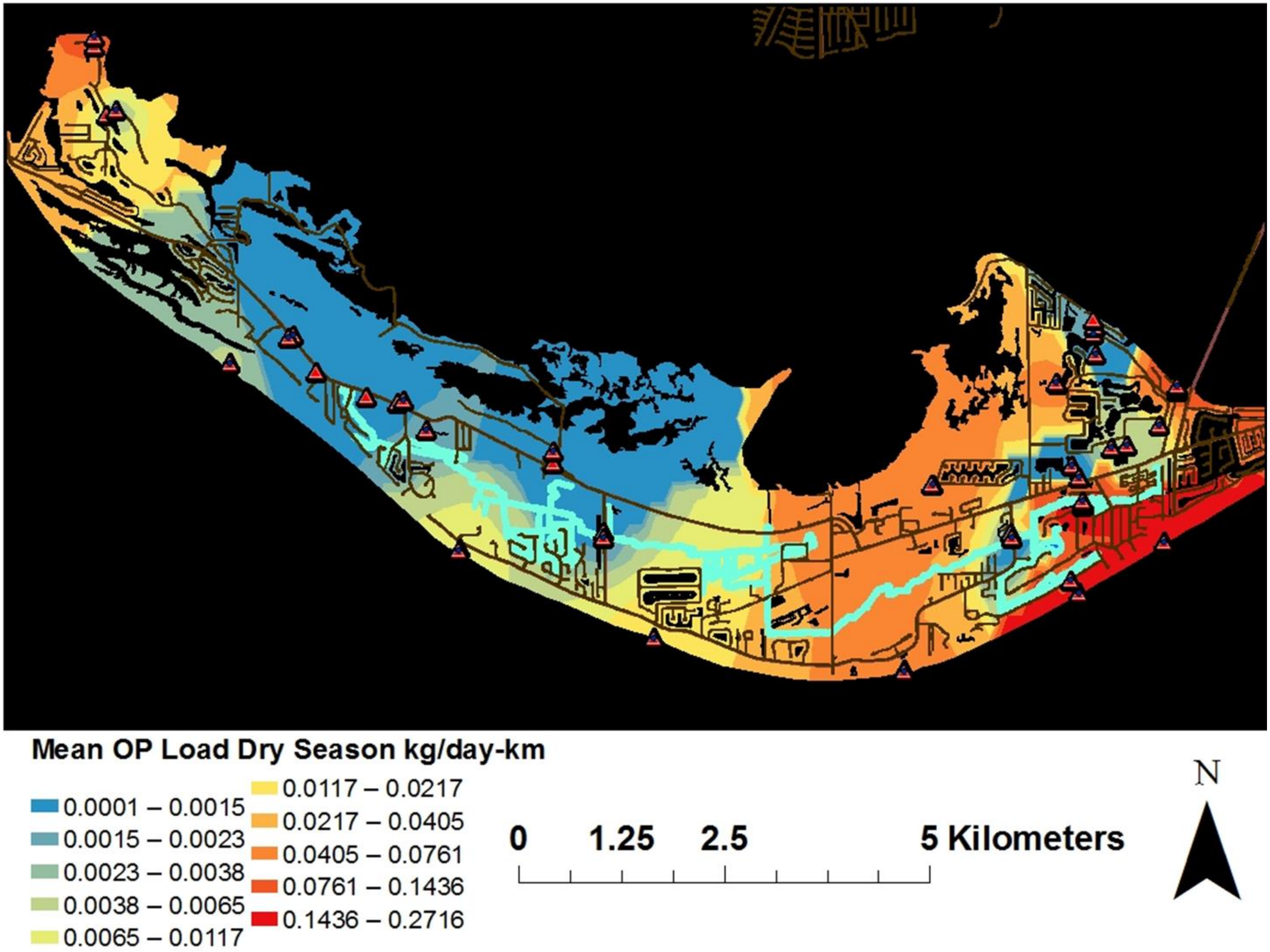

Figure 48. GIS-derived map of mean dry season OP loading produced from interpolation of surficial aquifer sampling results and flow estimates. Red color indicates higher loading rates to surface waters while blue color indicates low loading rate.

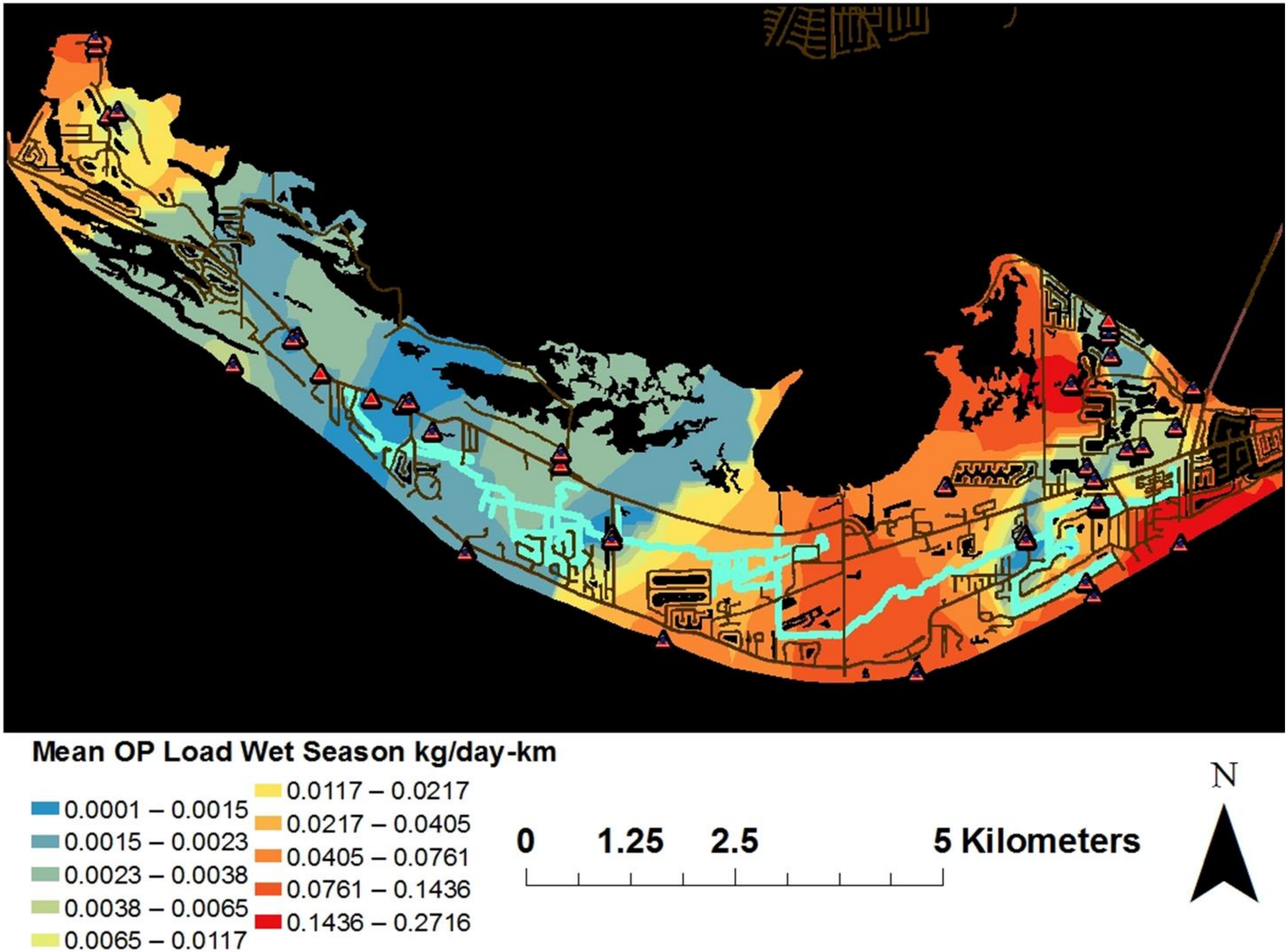

Figure 49. GIS-derived map of mean wet season OP loading produced from interpolation of surficial aquifer sampling results and flow estimates. Red color indicates higher loading rates to surface waters while blue color indicates low loading rate.

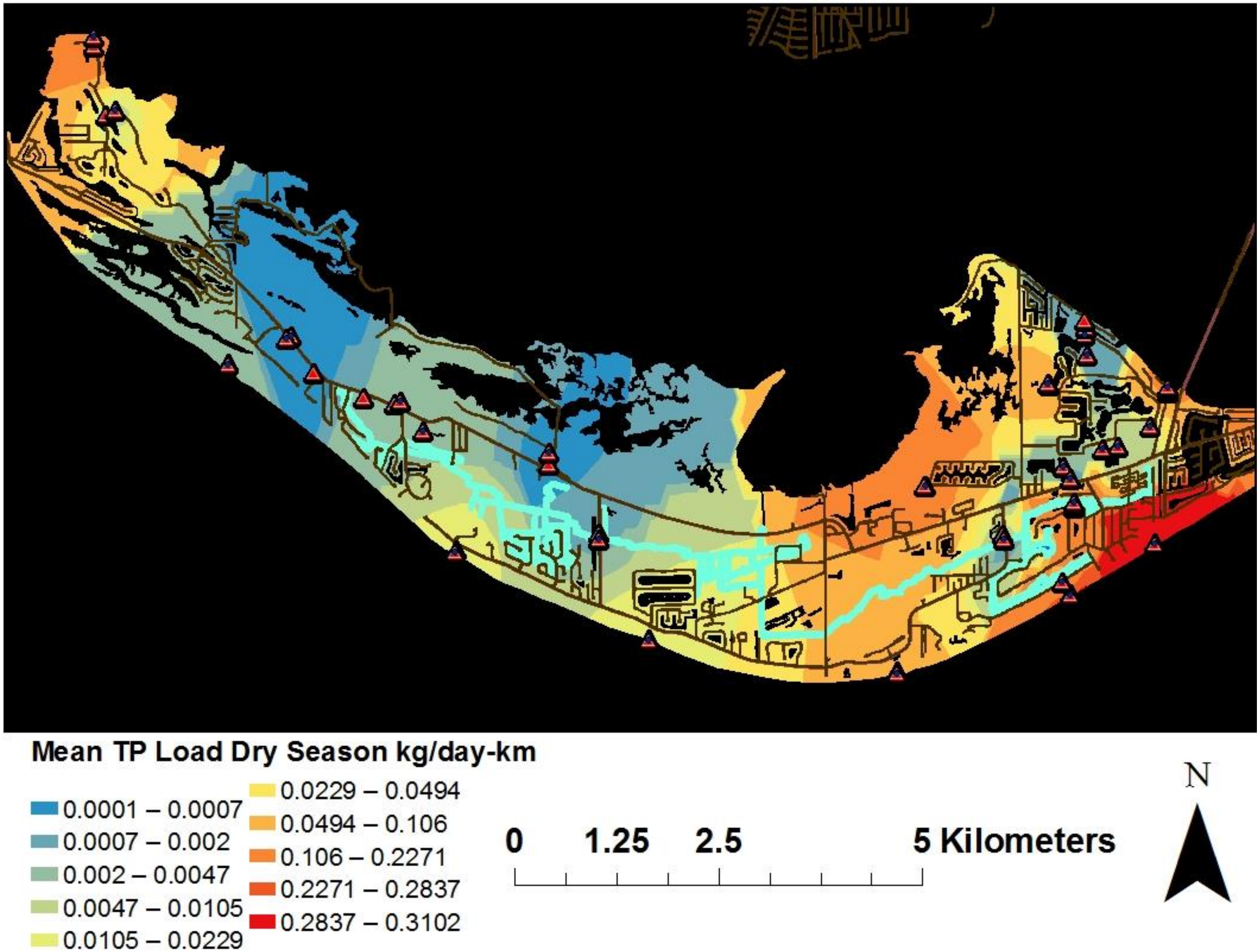

Figure 50. GIS-derived map of mean dry season TP loading produced from interpolation of surficial aquifer sampling results and flow estimates. Red color indicates higher loading rates to surface waters while blue color indicates low loading rate.

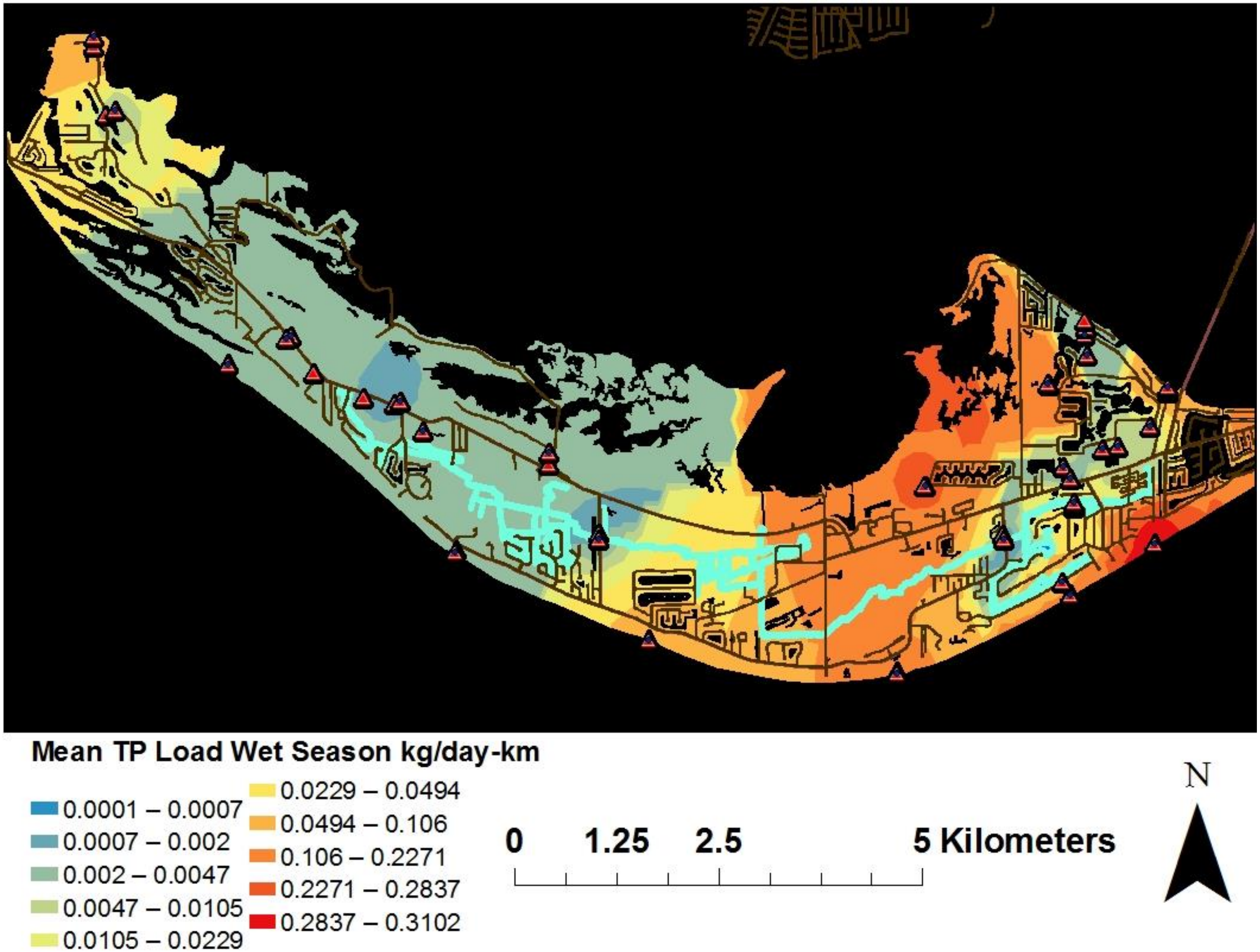

Figure 50 a. GIS-derived map of mean wet season TP loading produced from interpolation of surficial aquifer sampling results and flow estimates. Red color indicates higher loading rates to surface waters while blue color indicates low loading rate.

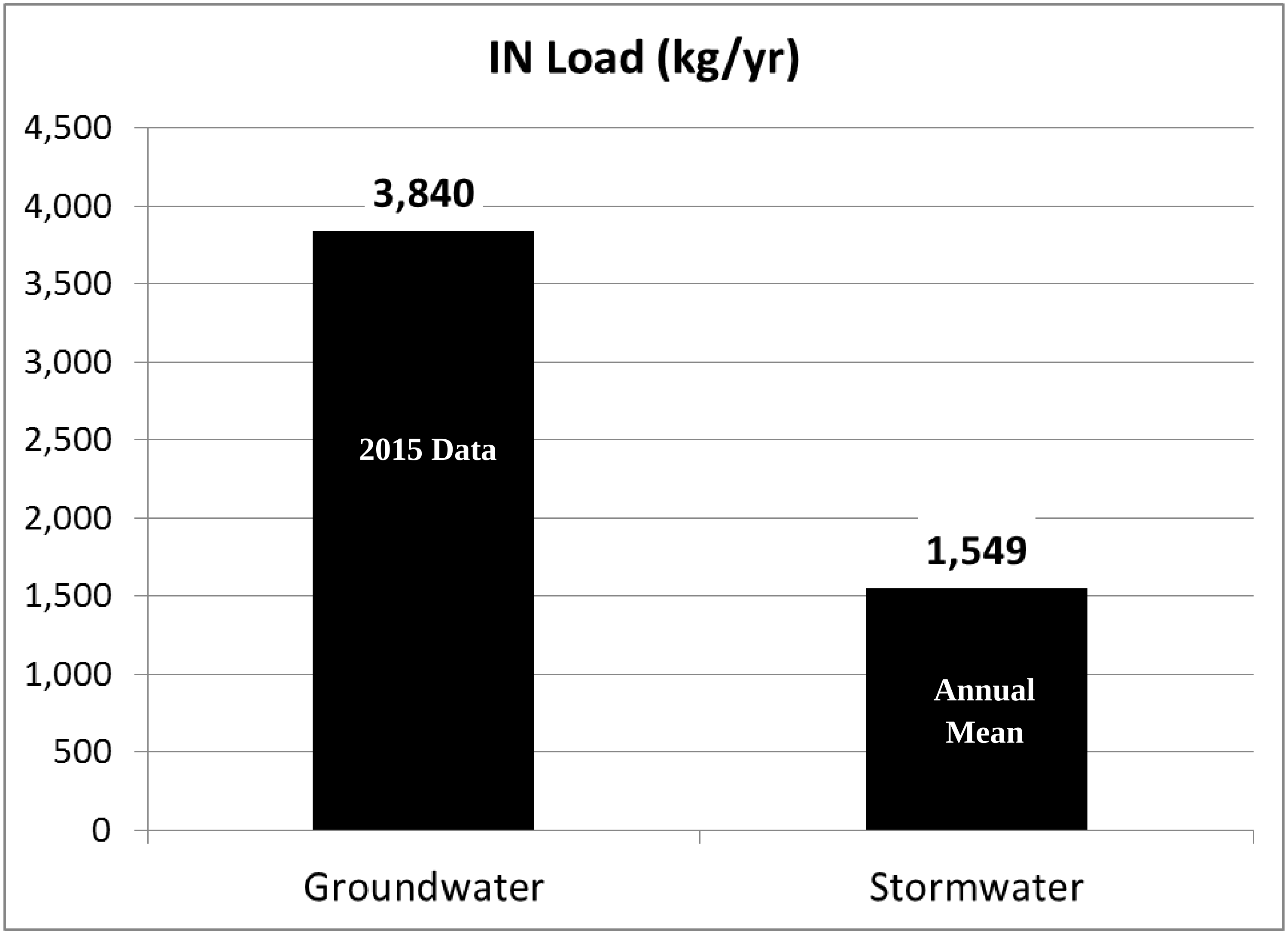

Figure 51. In load from surficial aquifer compared to annual average stormwater runoff load.

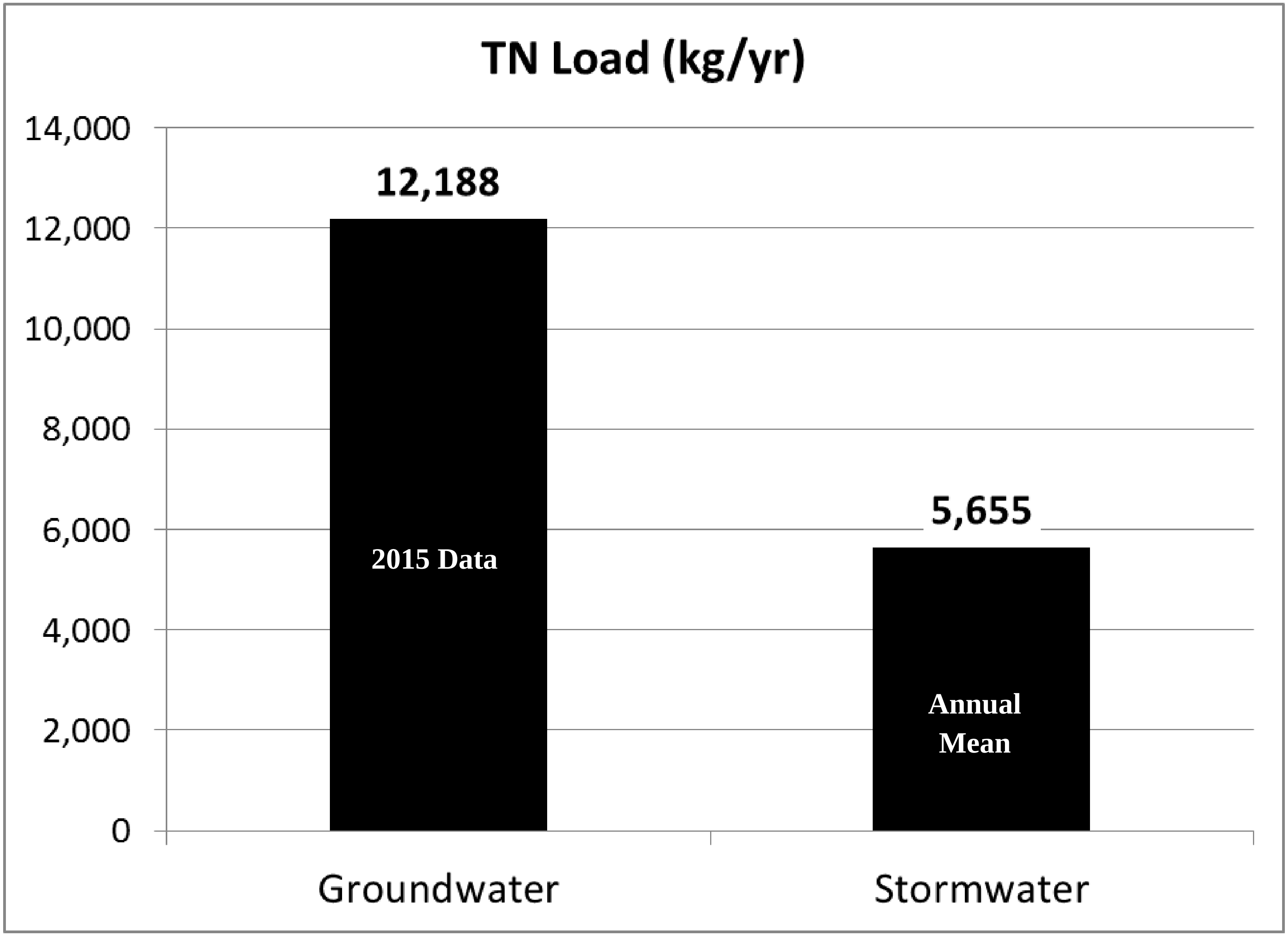

Figure 52. TN load from surficial aquifer compared to annual average stormwater runoff load.

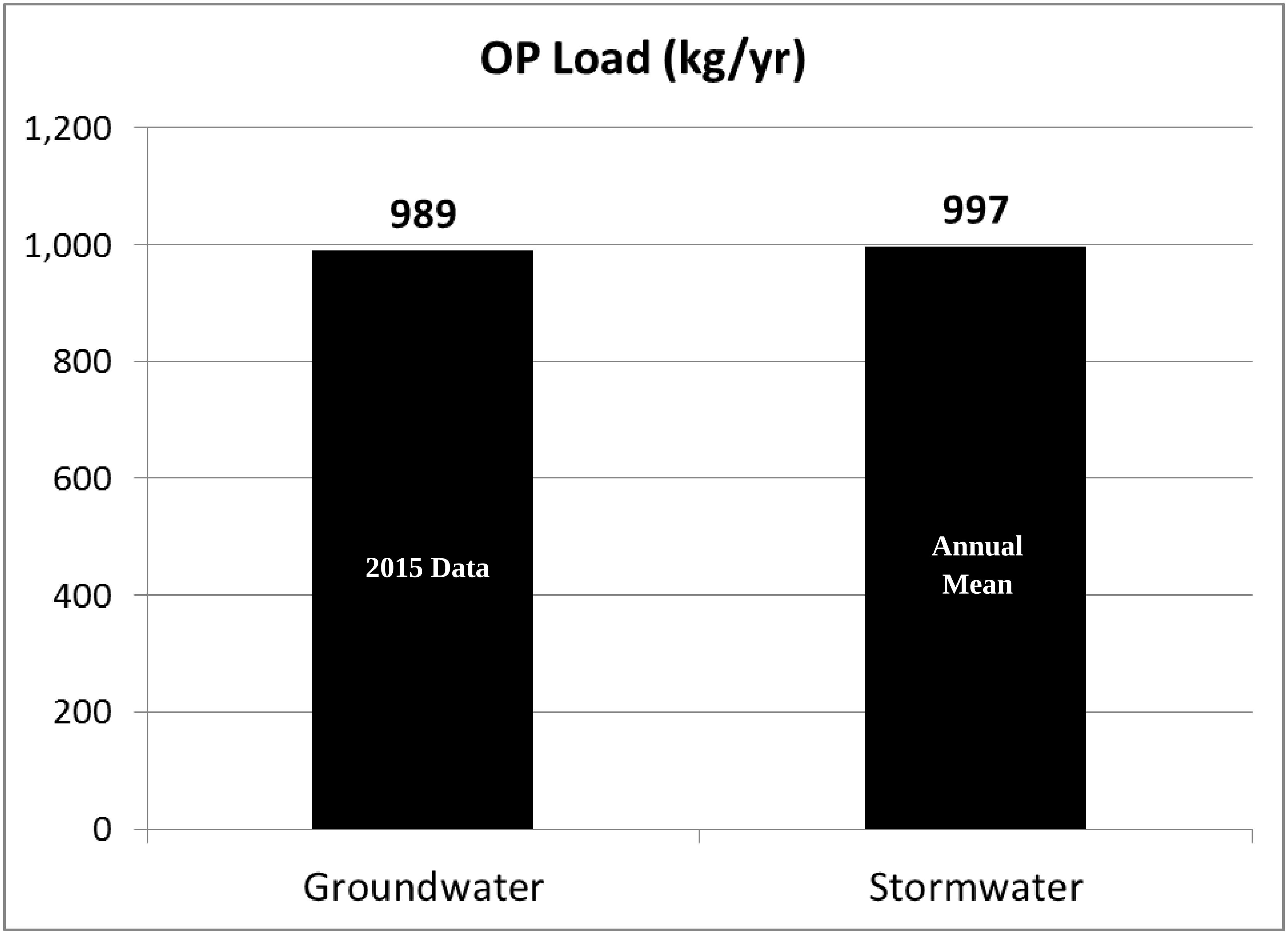

Figure 53. OP load from surficial aquifer compared to average annual stormwater runoff load.

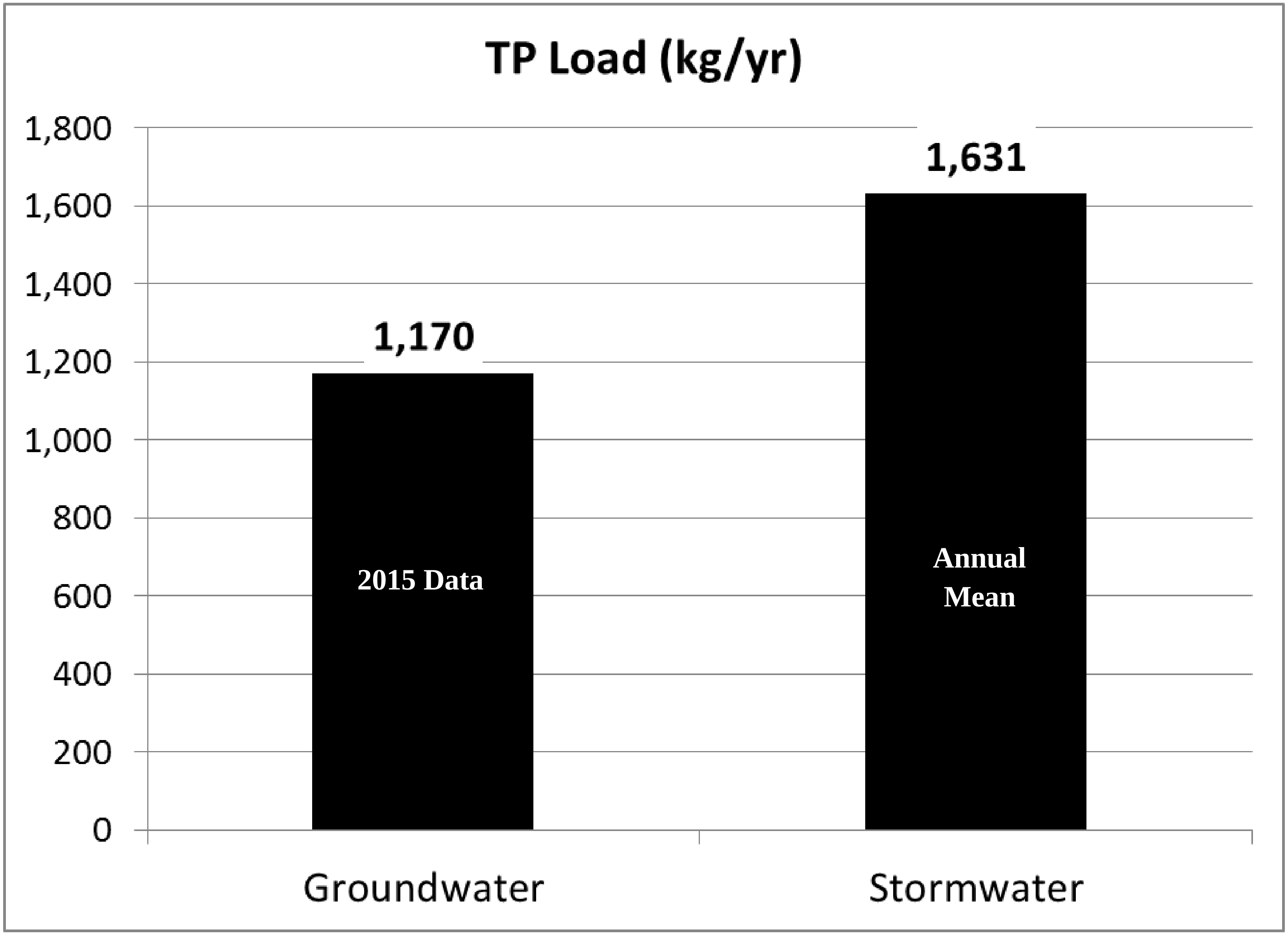

Figure 54. TP load from surficial aquifer compared to average annual stormwater runoff load.

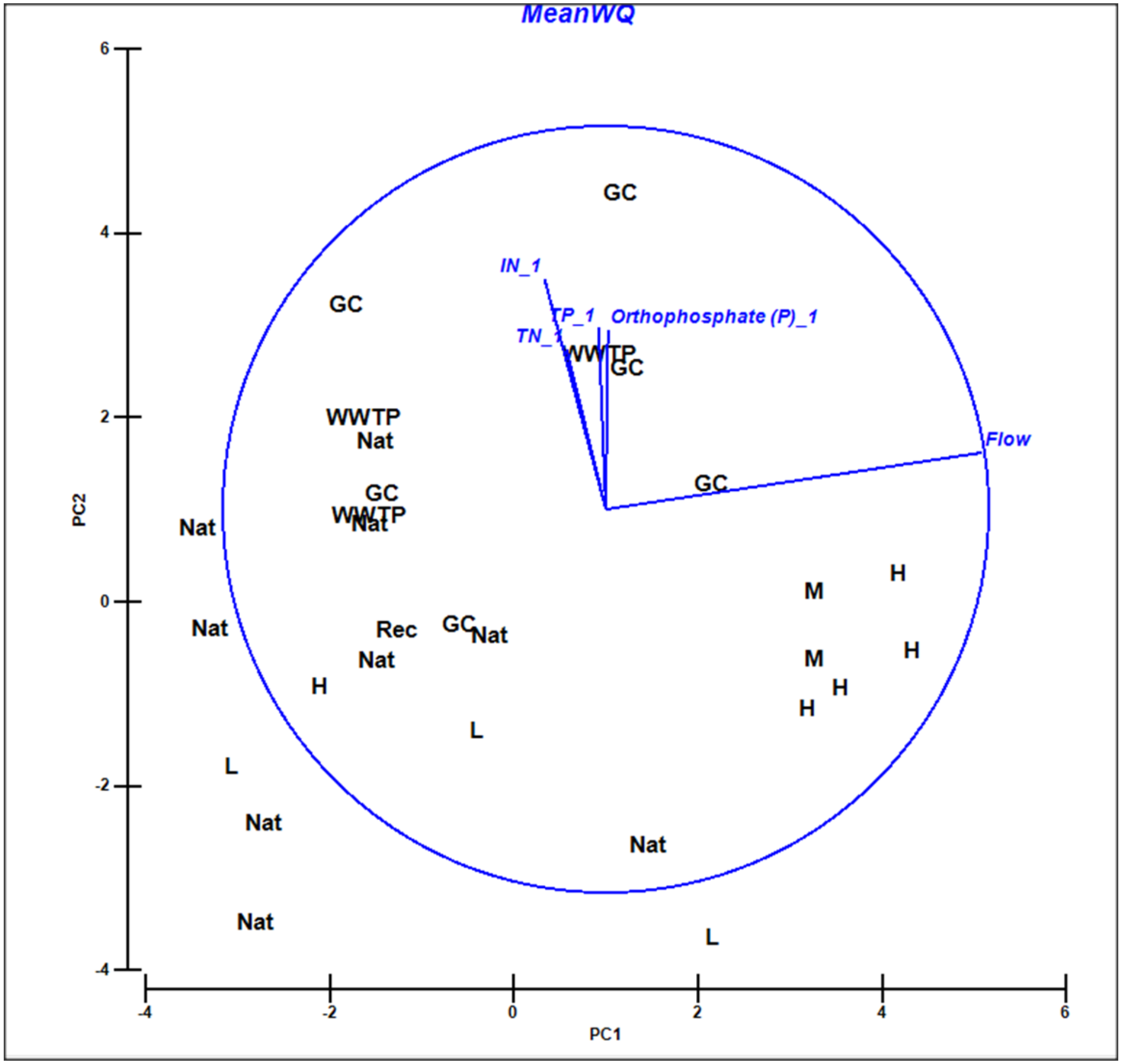

Figure 55. PCA using nutrient concentration and flow data plotted by land use type. High flows are toward right and high concentrations are toward top. Highest loads (and most concern) are toward top and right.

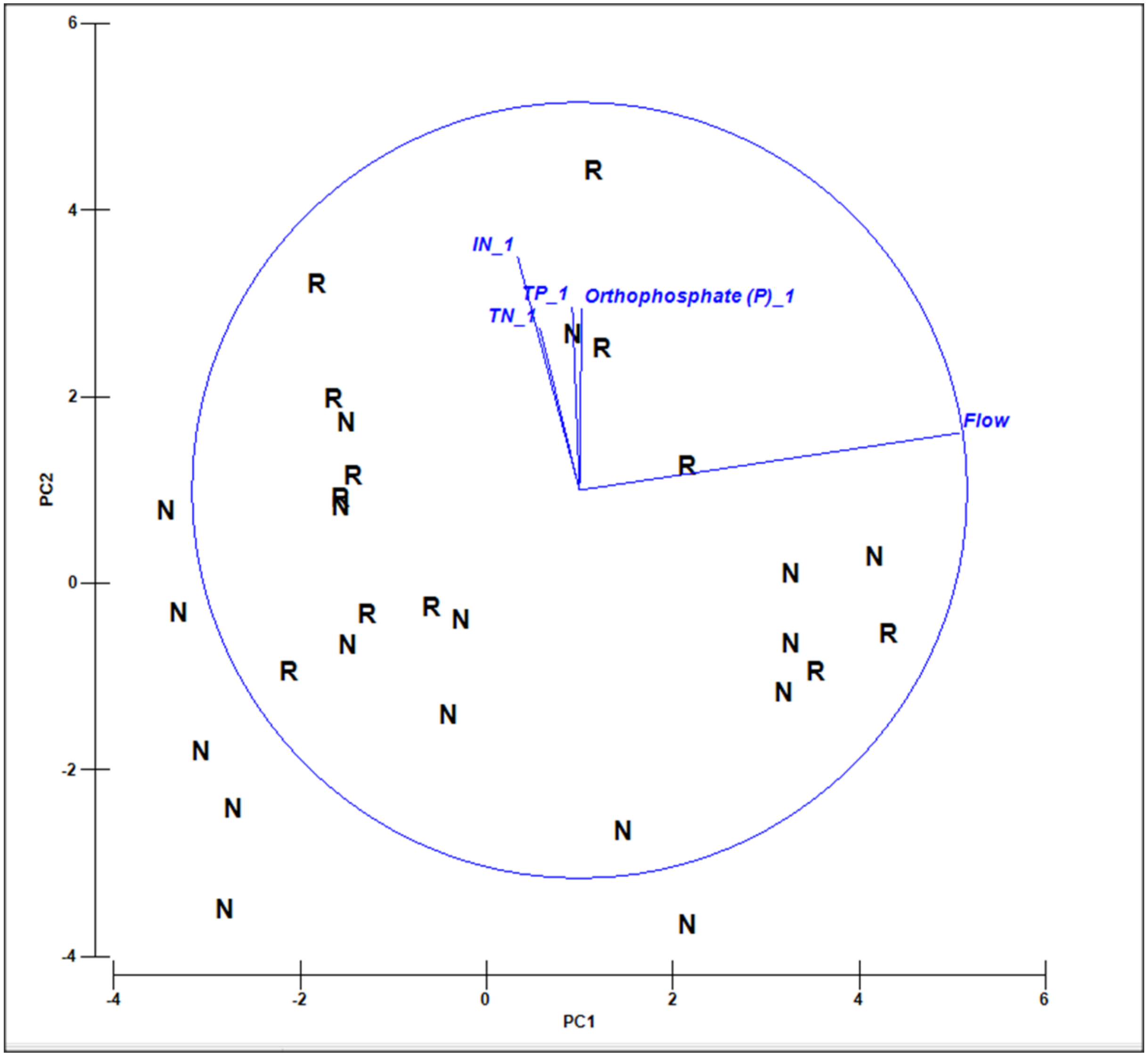

Figure 56. PCA using nutrient concentration and flow data plotted by use or non-use of reclaim water for irrigation. High flows are toward right and high concentrations are toward top. Highest loads (and most concern) are toward top and right.

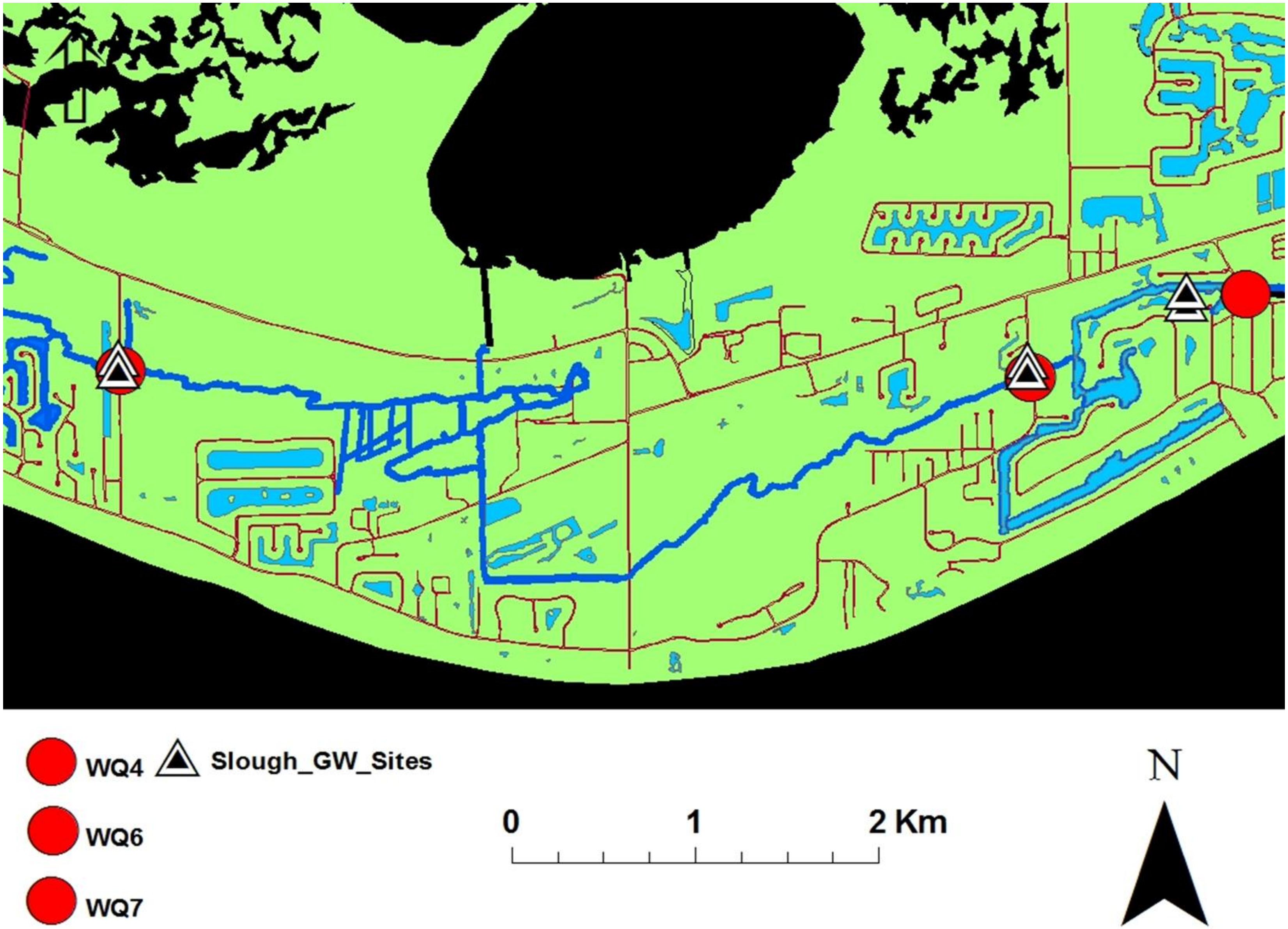

Figure 57. Location of surficial aquifer monitoring sites (triangles) adjacent Sanibel Slough shown with City of Sanibel's NPDES surface water monitoring sites shown with red points.

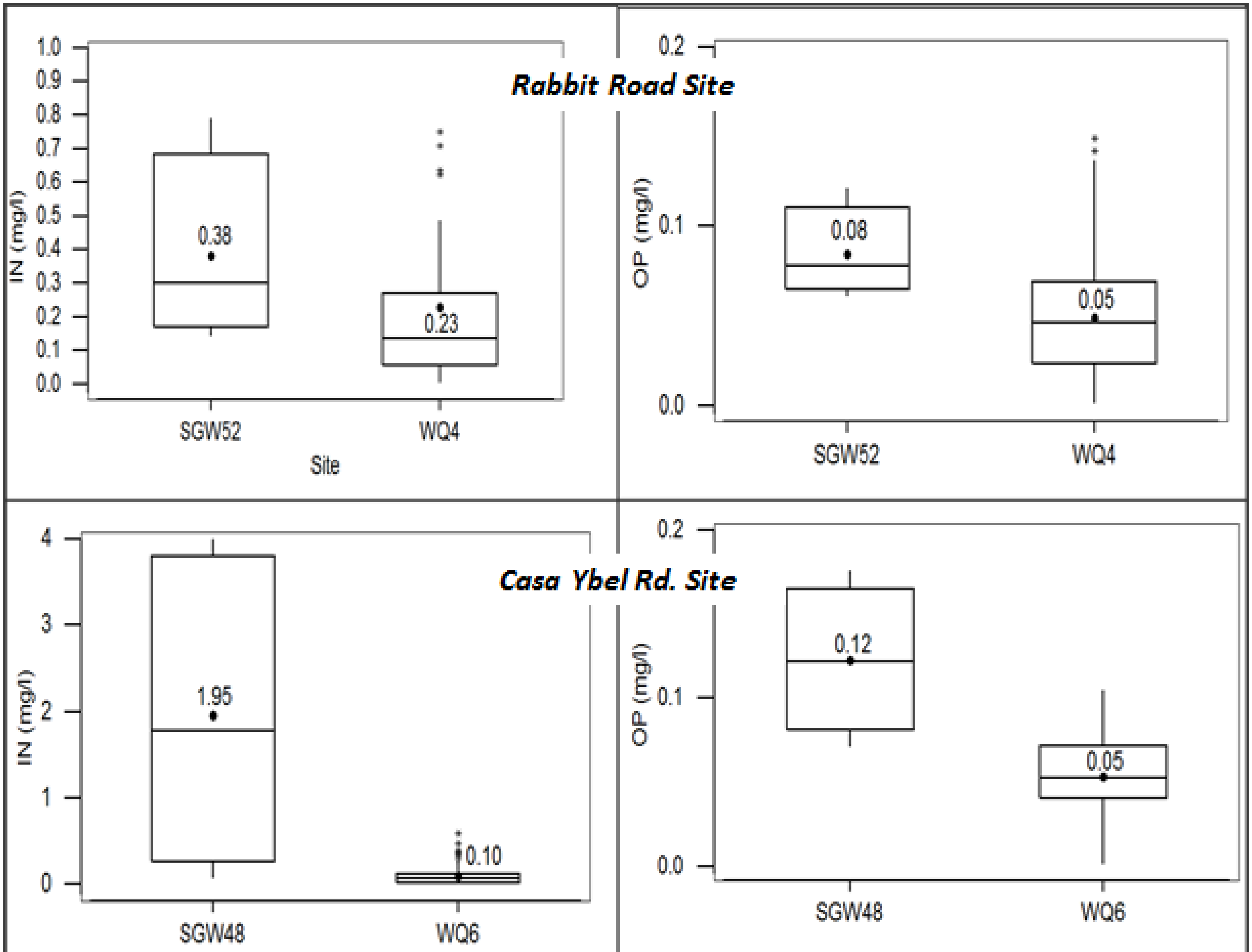

Figure 58. Comparison of mean surface water quality data from Sanibel slough (WQ) to mean surficial aquifer data from groundwater site adjacent surface water sampling site.

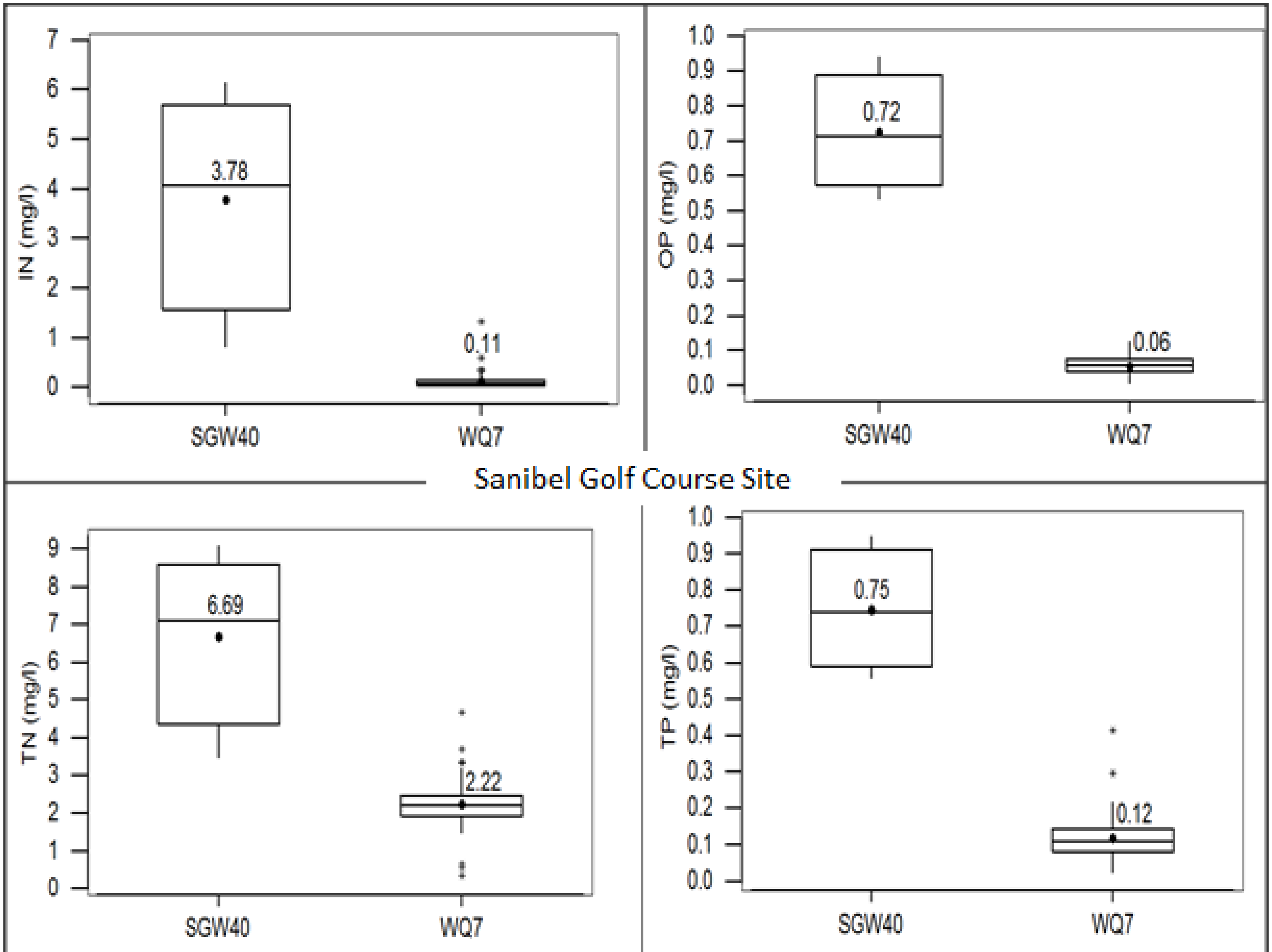

Figure 59. Comparison of mean surface water quality data from Sanibel slough (WQ) to mean surficial aquifer data from groundwater site adjacent surface water sampling site near Sanibel golf course..

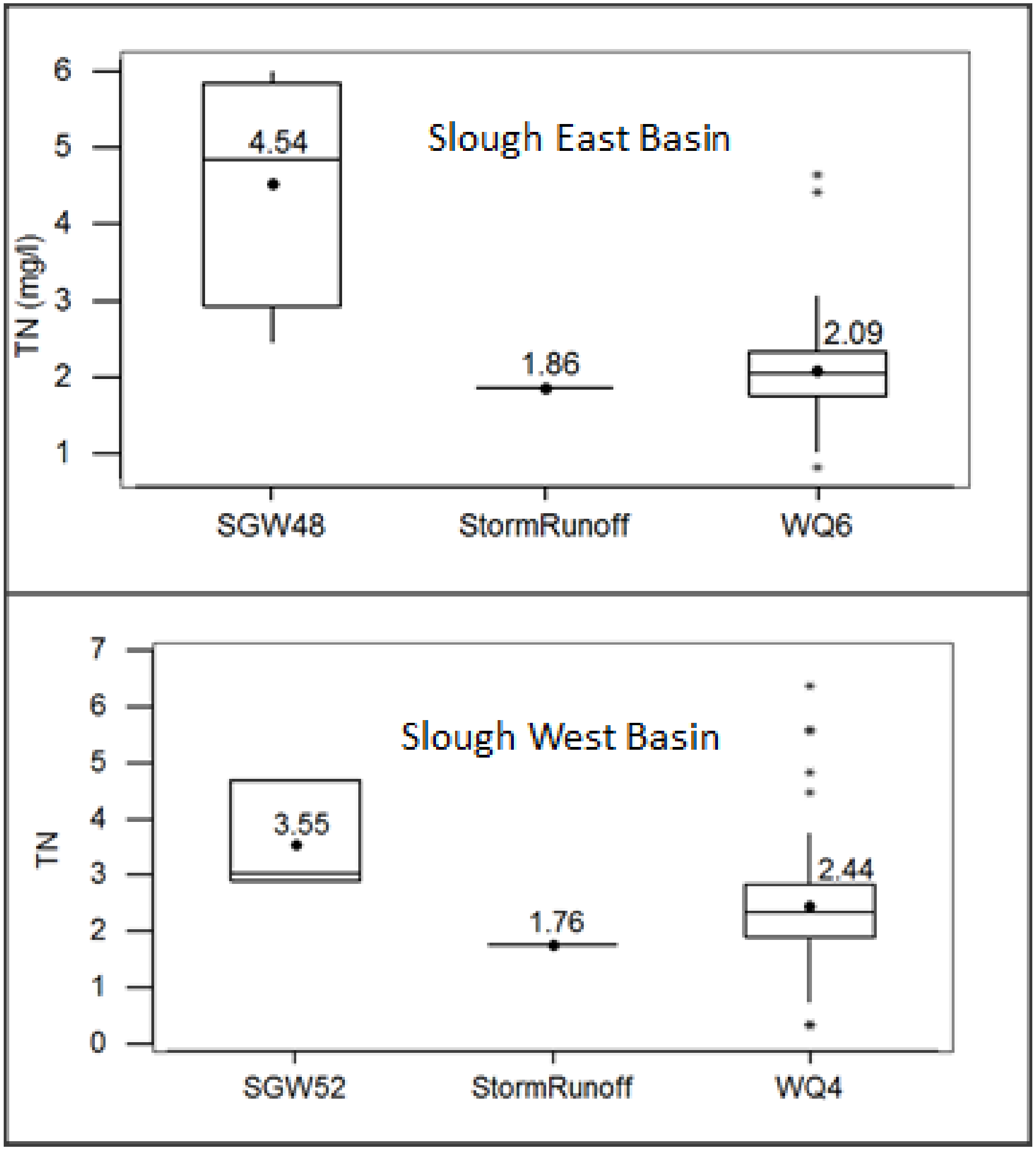

Figure 60.The diluting effects of stormwater runoff into Sanibel Slough. WQ sites are surface water sites on Sanibel Slough and SGW sites are groundwater sites adjacent Sanibel Slough.

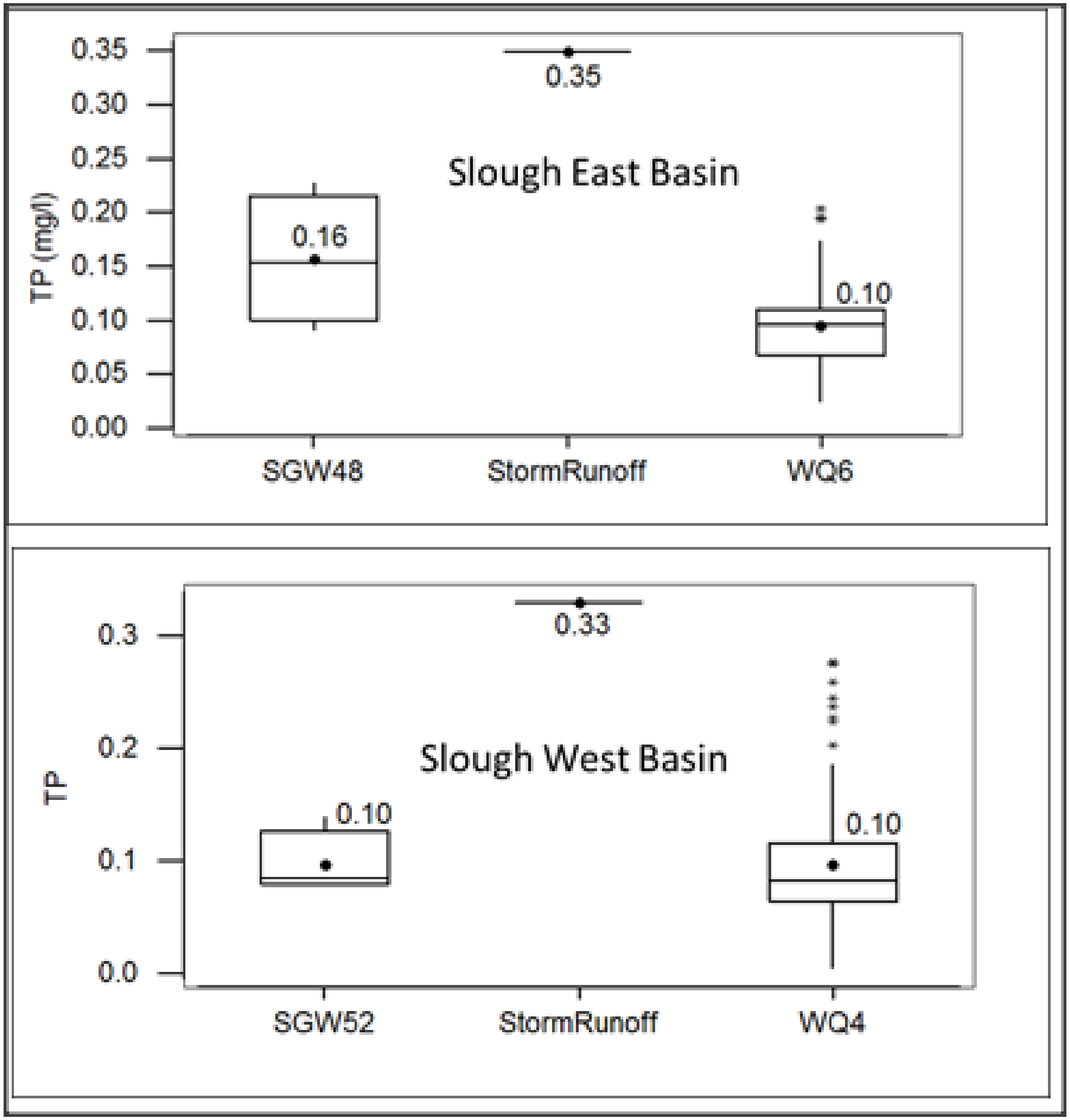

Figure 61. The loss of P to sediments in Sanibel Slough and to soil above the surficial aquifer (SGW) is evident in the lower concentrations of P in aquifer and surface water on Sanibel Slough (WQ sites).